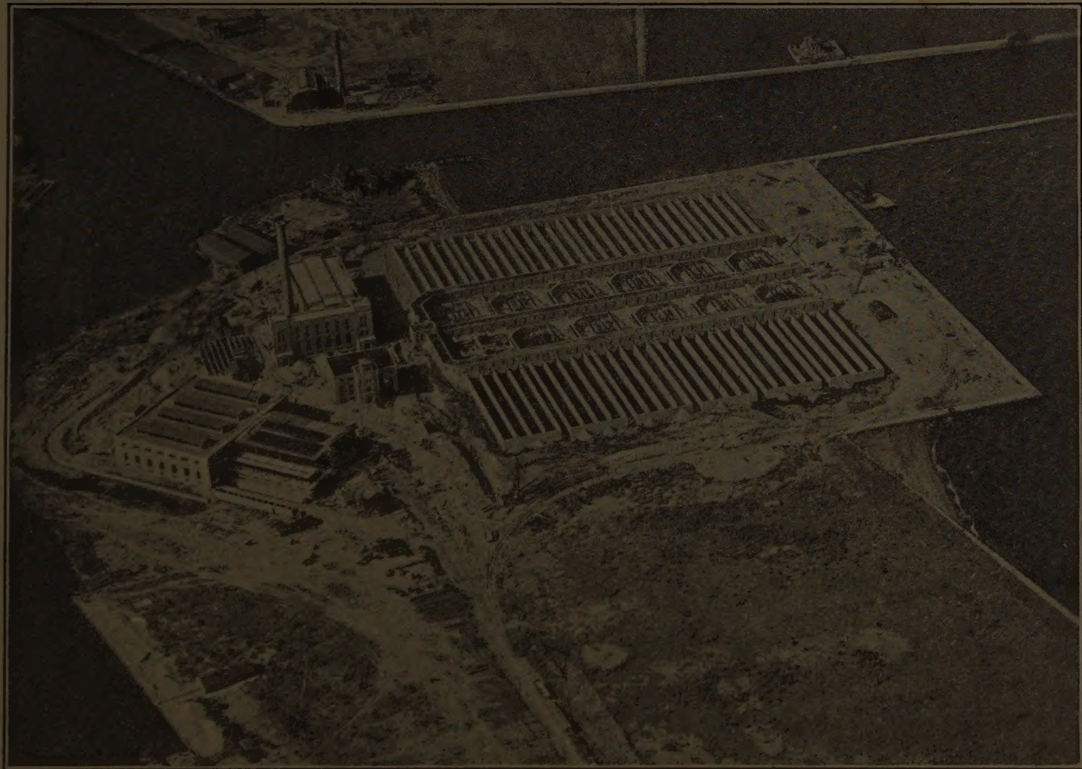
SOLVING SEWAGE PROBLEMS



(*Frontispiece.*)

Aeroplane view of Milwaukee activated sludge treatment plant.

SOLVING SEWAGE PROBLEMS

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FIRST EDITION

McGRAW-HILL BOOK COMPANY, INC.
NEW YORK: 370 SEVENTH AVENUE
LONDON: 6 & 8 BOUVERIE ST., E. C. 4
1926

PRINTED IN THE UNITED STATES OF AMERICA

THE MAPLE PRESS COMPANY, YORK, PA.

PREFACE

About a year ago, when, at the request of the publishers, the authors had about half finished the revision of Fuller's "Sewage Disposal," 1912, it had become clearly apparent that it would be preferable to prepare an entirely new book to stress the recent developments in theory and practice, making only brief reference to the older processes now adequately described in other books.

This new volume is intended to set forth concisely the fundamental principles of the subject. Sufficient details as to the arrangements of new plants are given to indicate recent advances in the art. Most of the chapters begin with a synopsis stating the more important viewpoints on the topic. The synopses are followed by more detailed text, varying in length depending upon progress made during the last few years. While the book is, therefore, a manual of the entire subject, particular consideration is given to natural purification of streams, basic design data, plain sedimentation tanks, sludge digestion processes, separate sludge digestion tanks, the collection and utilization of gas, screens, trickling filters, the activated sludge process, and industrial wastes. Those are the subjects in which city officials and their engineering advisors are now most often interested.

Since the World War there has been substantial progress in solving sewage problems. Rapid increases in population of American cities make the problems more pressing now than ever before. Their solution depends fully as much on administration and finance as on technical aspects. The latter can be mastered, if the former are attended to. One of the objects of this book is to inform administrative officials as to the problems, and the first three and the last chapters are written with that end particularly in view.

The manuscript for this book was drafted and edited with the aid of our principal staff members as follows: Elmer G. Manahan, James C. Harding, Fred G. Cunningham, C. A. Emerson, Jr., and Wellington Donaldson. We were also aided in the preparation of the activated sludge chapters by William R.

Copeland, for 12 years chief chemist of the Milwaukee Sewerage Commission. Abel Wolman, Chief Engineer of the Maryland State Health Department, was of great assistance in the editing of the entire manuscript and in the revision of proofs, as well as in the preparation of material for the chapters on gasification, gas collection, separate sludge digestion, broad irrigation, and fish ponds, and the appendix on phenol wastes treatment.

In the revision of proofs we had the benefit of criticisms and suggestions, particularly on engineering subjects from Langdon Pearse and Asa E. Phillips; on biochemical subjects from F. W. Mohlman, W. Rudolfs, and J. K. Hoskins and E. J. Theriault and on the first three chapters from N. Doris Palmer.

We made free use of material contained in official reports and technical papers and desire to acknowledge the invaluable assistance of such material. We also desire to express our thanks to the large number of workers in this field of sanitation, both in America and in Europe, who kindly assisted us. Most of the illustrations were prepared by B. C. Richardson. The index, proof-reading and checking of tables were largely the work of Rose Barkan.

G. W. F.
J. R. McC.

New York, N. Y.
July, 1926.

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SOLVING SEWAGE PROBLEMS

CHAPTER I

OUTLINE OF PROBLEMS

Sewage is the spent water supply of a community, together with those human and household wastes which are removed by water carriage, supplemented in some instances by street washings and industrial wastes.

The sewage problem may be broadly defined as how best to prevent and to remedy objectionable conditions in streams, lakes and tidal waters due to pollution by sewage and industrial wastes.

SCOPE

The pollution problem in the United States is rapidly increasing in seriousness. Between 1890 and 1920 the population in incorporated municipalities grew from 25 million to 64 million. The relative increase in the number served by municipal sewers was doubtless larger. Accompanying this change has been an even more rapid growth in industries discharging noxious wastes into the watercourses. Over four times as much polluting matter reaches American waterways now as thirty years ago. These increments in pollution have far outstripped reductions due to purification. The foul condition of many streams at present is only too apparent. Little imagination is needed to picture what the situation will be in another generation if pollution is again allowed to increase fourfold.

The major harmful effects of pollution have been excellently summarized by Monger[1] as follows:

1. The menace of a contaminated public water supply.
2. The creation of nuisance otherwise affecting public health and comfort.
3. The damage to property with resulting depreciation of values.

[1] Address before American Health Congress, Atlantic City, May 20, 1926.

4. The killing of fish and other natural stream life.
5. The damage to livestock.
6. The impairment of recreational facilities and destruction of bathing places.
7. The damage to public and private river and harbor improvements and navigation. (As by shoaling from sewage deposits.)

These effects are self-explanatory and practically every person in the country has suffered from or been aware of stream pollution.

Year after year thousands of persons sicken and die from typhoid fever, a water-borne disease. The main barrier against sweeping epidemics of typhoid, cholera and other water-borne diseases has been the purification of water supplies. In some cases, however, increasing pollution overtaxes the purifying powers of waterfilters and cities are being driven to seek new water supplies. Complication also comes from certain types of industrial wastes producing bad tastes which cannot be removed by filtration and water consumers then frequently drink polluted water from neighborhood wells.

Other nuisances of less objectionable, but still of important, character must be considered since they affect public comfort. There are in addition reliable evidences of considerable damage to property values due to faulty disposal of human and industrial wastes. To the agriculturist the damage to livestock by indiscriminate and uncontrolled disposal of wastes is a problem of practical significance.

Conservationists and sportsmen are concerned in this problem because of the detrimental effect which some materials may have upon fish and other natural stream life. More and more the American public is concerning itself with the protection of its recreational facilities and particularly with the avoidance of damaging effects to bathing places from human wastes.

Engineers can design and build effective remedies for these problems and this book has for its purpose a description of the details both as to the nature and correction of pollution by wastes.

EARLY DEVELOPMENT

In early days each household disposed of its filth as best it could. Cesspools for household wastes were officially recognized by sanitary authorities and there was little or no supervision of the disposal of the contents. In large towns polluting matters

accumulated near the dwellings and leached into the soil, unless carting to land was readily negotiable.

The use of waterclosets, effectively established in England, in 1810, rapidly increased in favor, with the introduction of pressure water supplies, making tight cesspools less practicable. Cesspool overflows led to street drains, frequently uncovered, and were discharged into the nearest water course. Under these conditions the cesspool, with its expense and difficulty of cleaning, passed from favor and underground sewers were gradually developed to take the place of the poorly arranged and badly built street drains. Household wastes in increasing proportions reached the watercourses. The resulting nuisances became a serious problem about the middle of the last century. The Nuisance Removal Act was passed in England in 1855 at the close of a severe cholera epidemic. It was about that date when the use of the watercloset was made obligatory in England.

The sewage problem thus took its modern form of pollution of waterways as distinguished from excessive accumulations of filth near dwellings. Pollution of waterways demands grave consideration from those interested in public health and in the maintenance of conditions of cleanliness appropriate to all civilized countries, in which advances in most matters have been so rapid during the past two or three decades.

COMPONENTS OF SEWAGE

General Classification.—Ordinarily sewage contains over 99.9 per cent of water. The remaining constituents, usually much less than 0.1 per cent by weight of the total product, include objectionable substances, which may be grouped as follows:

1. Floating solids.
2. Fats and oily products.
3. Settleable solids.
4. Non-settleable putrescible matters.
5. Bacteria.

A large proportion of the impurities found in sewage is inert. In fact 50 per cent or more of them may be unobjectionable, dissolved mineral matter coming from the water supply itself or from seepage water entering the sewers through leaky joints. Such substances naturally vary in amount in different sections of the country, depending upon whether the water in question is soft or hard.

The Metropolitan Sewerage Commission estimated that the dry suspended solids in New York City sewage contained, per thousand population annually, 14 tons of feces, 8 tons of toilet paper and newspaper, 11 tons of soap and washings, 8 tons of street wastes, and 4 tons of miscellaneous substances; a total of 45 tons.

English chemists have studied the quantities and fertilizing constituents of feces and urine for several generations. Way found that one adult voids in 24 hours about ¼ of a pound of feces and 3 pounds of urine. As in 4 ounces of feces there is one ounce of dry matter, nearly 23 pounds of dry solids result per annum per person. In 3 pounds of urine there are 1½ ounces of dry matter, making from this source nearly 34 pounds per annum per person. The ammonia from the 23 pounds of feces amounts to 1.60 pounds, and from the 34 pounds of urine 8.12 pounds, or a total amount of 9.72 pounds of ammonia per person annually. One adult furnishes about 5½ pounds of phosphates per year. Briefly, 57 pounds of dry matter are produced per year, containing 10 pounds of ammonia and 5½ pounds of phosphoric acid.

The above five classes of objectionable substances found in sewage may be briefly described at this point.

Floating Solids.—These are the substances, from waterclosets, kitchen wastes and street washings, which float on the surface of the water and reveal to the observer their sewage origin. They are probably the cause of complaint by the general public more frequently than are bacteria, which are far more dangerous. Their presence is a violation of ordinary concepts of cleanliness, and in many localities has done much to stimulate movements toward sewage treatment and river cleaning.

Settleable Solids.—The great bulk of suspended matters in sewage deposits in fairly quiet water. As the current in the waterway increases in velocity the conditions for deposition of solids become less favorable. In many streams sewage solids build up sludge banks during periods of low flow and low velocity. Boats stir up these accumulations and bring about offensive odors from the putrefying deposits. Lowering water levels frequently reveal objectionable banks of evil-smelling sewage mud. These deposits are justly objected to by the public, notwithstanding the fact that flood flows scour them away more or less completely.

Fats.—Oils, fats and greases come from kitchen wastes and manufacturing plants. Some are solid and others emulsify in water; some subside and others form a thin floating film known as "sleek" which gives a dirty, objectionable appearance to the water when it is not disturbed by wave action. Gas and oil works generally contribute far more than domestic sewage to complications of this sort. Manufacturing plants, particularly wool-scouring works, also furnish their quota.

Non-settleable Putrescible Matters.—In addition to the above substances there are the soluble organic matters and those components which are in a colloidal or finely divided condition. These substances settle only slightly or not at all and, by decomposing, deplete the oxygen which is dissolved to a limited extent in practically all natural waters. If present in quantities exceeding a certain limit they bring about putrefaction. In consequence a body of water receiving an excess of such discharges turns black and gives off objectionable gases and putrefactive odors due to the putrescible substances under discussion.

Bacteria.—Sewage contains millions of bacteria per cubic centimeter, most of which are not only harmless, but important in the economy of nature through their scavenging work. Some, however, are dangerous and may cause infectious diseases. Many of them play an important role in the decomposition of sewage, both as to oxidizing benefits and putrefactive nuisances.

NUISANCE ASPECTS

Originally sewage was conveyed to the nearest watercourse, although some early attempts were made to utilize its manurial value. As the contributing population increased, many important streams throughout the world became and remain grossly poluted, due to overtaxing of the limited diluting and purifying capacity of the watercourse. Such limitations are revealed by consequent putrefactive products with their attending bad odors, and by other nuisances varying in kind and degree.

Scum-covered Watercourses.—At numerous cities in earlier years, watercourses were so overburdened by the discharge from sewers that gas-lifted solid matters formed a thick scum on the surface. One of the branches of the Chicago River was known locally as "Bubbly Creek," and the scum became so thick that persons could walk upon it. Gowanus Canal in Brooklyn is

another stream which at one time contained upon its surface a vast amount of sewage solids.

When watercourses once reach such a condition it is a difficult matter to correct the cumulative effect, either in the waterways themselves or in the influence of such conditions upon surrounding areas and their property values. Experience in Europe, as well as in this country, shows that corrective steps ought to be taken long before these extreme results appear.

Sludge Banks—Sewage Mud.—The United States Government has jurisdiction over the entrance into navigable waters of those substances which cause shoaling. It is in a position to call upon the contributors of sewage solids (sludge) interfering with navigation to remove from designated areas a quantity equivalent to that which they discharge.

When Ambrose Channel in New York harbor was dredged to provide a waterway of suitable depth for modern ocean-going steamers, sludge banks in places were said to have been 8 to 10 feet or more in depth. Their formation and location came about in a more or less haphazard fashion, depending upon currents, winds and other factors.

Along water fronts objectionable conditions frequently arise from accumulations of coarse sewage matters deposited in the water. When boats stir up these black deposits, with their attending foul odors, one of the potent reasons for remedial measures is found.

In warm weather sludge deposits putrefy actively, causing more or less bubbling on the surface of the water. With the rising gases sewage solids come up and produce the scum-covered watercourses previously mentioned.

Obviously the velocity of flow of the water is a factor affecting the formation and permanency of sludge banks. In many waterways accumulations are swept out by flood flows to varying degrees of completeness. For instance, in the Cuyahoga River at Cleveland, just above its entrance to the lake, marked signs of active decomposition were evident through a period of many years. The severe floods of 1913 in that section of the country so thoroughly washed out sludge accumulations that putrefactive conditions for quite a period after the flood were better than previously. In the absence of such scouring velocities dredging may be employed.

When it is realized that there had been deposited in the Chicago Drainage Canal, after about eleven years of operation, over

2,330,000 cubic yards of sludge from sewage, from which a portion of its sludge had previously been deposited in the branches of the Chicago River, it should be evident that the question of sewage mud assumes large proportions in the deterioration of streams.

Black Putrefying Watercourses.—Nuisances from sewage-polluted waterways are not restricted to thick scum formation or deposition of large banks of sewage sludge or mud. Many a waterway is so overtaxed with its load of sewage that the main body of water is black and putrefying and consequent odors are noticeable for a considerable distance.

Persons familiar with various arms of New York Harbor and with the lower Passaic River are well aware of the serious nuisance arising from overtaxing water with organic matter.

The fact should be noted that, after a stream acquires this condition, it is a time-consuming and expensive undertaking to make remedial measures effective. Hence, if such instances of gross pollution are to be avoided, as should always be the case, it is necessary for the authorities to keep informed as to the margins of safety and to install corrective measures in time to avoid such extreme situations as just mentioned.

Polluted Foreshores.—Sewer outlets in some cases do not extend to the water's edge at low stages, with the result that offensive conditions arise along the shore, especially from sewage mud on tidal flats. Similar results are to be found on river banks uncovered during low water stages.

In earlier years little attention was paid to extending sewer outlets so that they would be submerged at all times. Such extensions do not correct water pollution, but they help the general situation by lessening shore pollution. Obviously, the performance of submerged outlets depends on depth and velocity of stream flow, as well as upon its relative volume.

Industrial Wastes.—It is not sufficient in these matters to consider only the flow of sewage coming from households and ordinary commercial establishments. Various industries in some localities exert a powerful influence upon results and limit the quantity of sewage that may be discharged properly into a watercourse.

At Chicago, the wastes from the stockyard district and the packing industry are estimated to have an organic content approximately equivalent to that of the sewage flow of 1,100,000 people. In Paterson and Passaic the local river is materially

and prejudicially influenced by the discharges from the textile establishments, which are large and numerous. Woolscouring wastes from the mills at Lawrence, Mass. likewise have brought about a definite deterioration in the character of the Merrimac River water below that city. Metal works, discharging liquids containing acids, iron and copper products, frequently control markedly the character of liquid discharged from sewers and that found in neighboring watercourses. These industrial wastes also are factors of great significance in sewage treatment arrangements.

HYGIENIC ASPECTS

The practice of disposing of sewage by dilution is related to disease, when sewage bacteria enter the bodies of human beings in cases where sewer outlets have too close a proximity to:

(*a*) Waterworks intakes, so that the supply is polluted and water filters and purification processes are overloaded.

(*b*) Bathing beaches.

(*c*) Shell fish layings.

(*d*) Ice.

The entrance of sewage into streams, lakes and tidal bodies of water creates nuisance primarily. Accompanying the organic filth and the millions of harmless bacteria, however, is a limited number of bacteria which are the specific causes of such diseases as typhoid fever, Asiatic cholera and dysentery. Modern theories of disease were not recognized by leading sanitarians until after 1880, and general recognition of the germ theory of transmission did not follow until the severe outbreaks of Asiatic cholera at Hamburg in 1892–3. It should not be inferred, however, that sanitarians prior to that date were not aware of the danger arising from stream pollution. In England, where sewerage and sewage disposal problems first received careful study, there was in vogue for some years prior to the germ theory of disease, an almost equally efficient viewpoint, namely, the filth theory of disease. Those in charge of the public health in England and in a limited number of places elsewhere were thoroughly alive to the danger of the pollution of streams used as public water supplies.

NATURAL PURIFICATION OF STREAMS

Persons have had the opinion for many years that running water would purify itself in the course of relatively short distances.

Some laymen indicated that streams would become free of pollution after flowing 5, 10 or 25 miles, quoting such and such persons of authority.

These fallacies were no doubt associated in the lay mind with belief in some mysterious oxidizing or purifying power of the air, particularly in mountain brooks or other turbulent streams where aeration was visibly caused by riffles or falls. These popular notions, not yet completely extinct, prevailed chiefly prior to the germ theory of disease. No doubt they were related to the absence of visible pollution, on the assumption that what was out of sight was out of mind. For this reason the pollution produced by mountain villages and by overflowing cesspools was popularly supposed to have no influence upon the quality of water a short distance below the point of pollution.

These extravagant views contributed to the loss of many thousands of lives, subsequent to the date when the germ theory of disease had become generally accepted by sanitarians and medical men. The error of such beliefs lies, of course, in the fact that disease germs in water will live in diminishing numbers for many days, and frequently the distances and time intervals assumed to have been adequate are far too short to insure the death of dangerous bacteria in transit.

Notwithstanding the errors in these beliefs, it is nevertheless true that natural agencies effect substantial purification in streams both as to destruction of disease germs and the oxidation of putrescible organic matter.

RELATION TO FISH LIFE

Fish will not live in streams highly polluted with sewage. This is due partly to the depletion of atmospheric oxygen naturally present in unpolluted water and partly to the poisonous substances either contained in the sewage or appearing as decomposition products incident to sewage pollution. In England, by the middle of the nineteenth century, the fish had quite generally disappeared from the lower reaches of a number of streams in the densely populated manufacturing districts. This led intentionally or otherwise to the policy of protecting very completely the quality of the upper reaches of the English streams and of dedicating the lower stretches to sewage disposal subject to the avowed purpose of maintaining substantial freedom from gross

nuisances. Under this policy fish life became and is now extinct in considerable lengths of British rivers.

On the continent of Europe and in America, streams are larger and the population is less dense than in England. It is a fact, however, that fish life has been restricted even in fairly large rivers for the reason stated above. Even in countries with large rivers, there are obviously many tributaries of relatively small size, and for this reason the fish question has been and still is a pertinent one in many areas. Such a question naturally must be considered from the standpoint of whether, after gross nuisances are eliminated, it is worth while to secure fish-thriving conditions in regions where ample fish may otherwise be easily secured. These and other questions of varying policies are discussed elsewhere herein.

SUMMARY OF DEVELOPMENTS

With the advent of pressure water supplies and waterclosets and the introduction of underground channels or sewers for the removal of household and other wastes, pollution of the waterways generally resulted where these facilities were adopted. In many instances rivers are of ample size, considering the population upon their watersheds, to assimilate sewage without substantial nuisances. However, in many streams of relatively small or medium size, pollution has occurred and still does occur in objectionable degree. These nuisances are not only of a gross type with respect to offense to sight and smell, but they also relate to the public health. The sewage problem is fundamentally one of preventing or abating such nuisances, by procedures widely varying in practice according to the available legal and other bases for procedure, the degree of pollution and local conditions.

England, with its small streams, dense population and manufacturing wastes, has for 50 years presented the most striking picture as to the proportion of household and industrial wastes which has been of necessity subjected to purification to keep the sewage situation within moderate control. In Germany there are limited areas, particularly in Westphalia, where sewage treatment has been a practical issue for many years, but, generally speaking, the German rivers are so large with respect to the tributary population that the German sewage problems have been far less pressing than in England or in certain of the eastern states

in America. Thus far corrective measures have been applied only to some of the more serious cases of pollution and there obviously remain throughout the world many watercourses which should now have the benefit of sewage treatment in order to put them on a less objectionable basis than now exists.

REMEDIAL MEASURES

During the past 75 years there have been notable changes and progress, both in theory and practice, as to means for treating sewage so as to prevent stream pollution, but they have been less striking than the changes in many other fields. In this chapter we shall outline the various stages through which treatment processes have passed and then summarize briefly the status of those methods now found most practicable. The different processes are discussed in detail in following chapters.

Stages in the Development of Purification Processes

Manure Program.—Beginning with the use of underground channels as replacements of cesspools, systematic efforts have been made, particularly in earlier years, to utilize commercially the manurial value of sewage. The many companies formed for this purpose have rarely, if ever, been successful. The amount of diluting water is too great to permit economic recovery of the fertilizing properties which sewage undoubtedly possesses in limited measure.

Land Treatment.—Beginning in 1857, an English commission reported that the distribution of sewage on land was a proper method of purification and, in fact, that it afforded the only means of preventing the pollution of rivers. A similar view was reported by Royal Commissions appointed in 1868 and again in 1882. Naturally the Local Government Board (The Ministry of Health since 1918), charged with the supervision of sewage disposal projects, adhered almost invariably to the recommendations of these commissions, regardless of how exceptional local conditions might appear. Although the principle of land treatment was adhered to, its practical application was made difficult by the generally non-porous character of the soil and, as a result, sewage disposal activities were retarded through a term of years. In fact, for many of the larger cities it was impossible to comply at reasonable cost with such demands. Where impervious tracts

were of necessity used, unsatisfactory results arose through inevitably bypassing at times into the rivers, as well as from odors caused by pooling on "sewage-sick" land. These circumstances caused the appointment of the last Royal Commission on Sewage Disposal, in 1898. It became recognized that so-called biological methods of treatment were practicable and that land treatment in some localities, at least, might be dispensed with. Today land treatment is not generally used although, where ample porous soil exists, satisfactory results are still obtained. The sewage farms[1] at Paris, Berlin, Nottingham and some other places have the reputation of being successful and satisfactory. Generally speaking, the method has largely disappeared.

Chemical Precipitation.—The 1870 report of the English Rivers Pollution Commission records chemical precipitation as a well established method. It was the outgrowth of many earlier patent processes which were aimed at the recovery of manurial values. Chemicals were added to coagulate the sewage in sedimentation tanks and thus effect substantially complete clarification. The method was extensively used in England and to a less extent in America. Beginning 15 years ago or more, it passed from favor. Tanks of old plants were used without chemicals, either as plain sedimentation or as septic tanks. Now chemical precipitation is rarely used except in cases where the sewage contains substantial quantities of trade wastes or where there are special needs for removing finely divided particles. Generally speaking, the effluent of chemical precipitation works will putrefy and the improvement over plain sedimentation is not commensurate with the cost. Furthermore, the use of biological methods, beginning shortly after 1890, made this process of questionable advisability for all ordinary local requirements.

Intermittent Downward Filtration.—Sir Edward Frankland investigated the processes related to the changes in sewage after it passed through beds of fairly porous sand. With the recognition of the action of micro-organisms, the reports on this process became more frequent and adequate. Such filtration was adopted in 1871, at Merthyr Tydvil, Wales, but the results were not particularly satisfactory. It made little progress in the displacement of irrigation or sewage farming in Europe and soon dropped out of view there. following the introduction of biological filters or bacteria beds. In New England and a few places else-

[1] Discussed further in Chapter XXX, Broad Irrigation.

where in the United States, beginning in the late eighties, intermittent sand filters came into quite general vogue where local deposits of fairly coarse sand were readily available. Outside of New England, this type of filter was rarely installed due to the absence of suitable sand deposits and to the cost of transporting sand from a distance. There are a number of sand filters in New Jersey and other eastern states installed in places where a high degree of purification is required, but there are no large sand filter plants outside of New England except at Saratoga, N.Y.

Septic Tanks.—These are sedimentation tanks, frequently covered, in which the sludge deposited is retained for some months and is thus subjected to liquefaction. They are of French origin. By the separation in this way of the suspended solids, an effluent is made more suitable for treatment on bacteria beds or for discharge into neighboring watercourses. In the middle nineties the septic tank came into quite general vogue in England and in America. Patent complications and the development of two-story tanks, in which the sludge is digested in separate chambers, terminated their popularity in America. The septic tank likewise gave place in England to the use of plain sedimentation tanks. If removal of the sludge is neglected, the sludge will in time be lifted by gas and disgorged into the effluent. If the detention period of the liquid is too long, the liquid becomes oversepticized and offensive. For these reasons and on account of possible odors septic tanks are not well suited for large communities.

Fine Screens.—Beginning about 1900, at many German plants the sewage was passed through self-cleaning fine screens having openings ⅛ inch in size or smaller. The purpose was to keep matters of obvious sewage origin from appearing in the rivers, most of which are relatively large. About 1912, fine screens came into use in the United States and have been installed at a number of large plants. They remove less suspended matter than plain sedimentation tanks.

Two-story Tanks.—Beginning about 1905, two-story tanks came into use: first, the Travis or Hampton tank and later the Emscher or Imhoff tank. These tanks are provided with trapped slots at the bottom of the sedimentation compartment, to convey the deposited sludge into a compartment below. In the lower or digestion chamber, the sludge is digested to an inodorous condition. The trap prevents the troubles experi-

enced in single-story tanks in the way of gas-lifted solids interfering with sedimentation and appearing in the effluent. The gas from the digestion chamber is released through vents either into the atmosphere or into collectors arranged to facilitate utilization of the gas.

Plain Sedimentation.—This process consists in the removal of settleable solids by sedimentation, unaided by chemicals, in tanks from which the sludge is withdrawn promptly enough to avoid putrefaction. It is the only treatment used in some English plants, where in numerous cases it evolved through the mere omission of chemicals from precipitation processes and through frequent removal of sludge from septic tanks. For the past 20 years, the method has been extensively used as an independent process, as a preliminary to oxidizing treatment and as final treatment following bacteria beds. It has lost ground at times through the vogue of two-story septic tanks but is established today as one of the most important features of treatment practice. Improved mechanical or other means for removing settled sludge, the advent of the activated sludge process which requires sedimentation as final treatment, and the growing practice of digesting sludge in separate tanks, have enhanced the status of plain sedimentation in recent years.

Separate Sludge Digestion.—The digestion of sludge to an inodorous condition in separate tanks, although not an independent treatment process, is one of the outstanding developments of the past 10 years. This method, in conjunction with plain sedimentation, competes with two-story septic tanks and in some cases doubtless has economic and other advantages thereover. It gives much promise as a helpful adjunct to existing sedimentation plants, where the disposal of sludge is often a problem. Collection and utilization of the gas from the digesting sludge provide both freedom from odors and opportunity for financial return.

Bacteria Beds.—For use where the porous deposits needed for sand filters are not available, efforts were made at the Lawrence Experiment Station of the Massachusetts State Board of Health to secure higher rates of treatment on relatively coarse material, such as gravel or other hard material. The results were reasonably satisfactory as to quality of effluent, but their adaptation to working conditions was due to British investigation. One type of bed known as the contact bed was operated by allowing the

bed to stand for a time filled with sewage and later slowly draining off the fairly well clarified and purified effluent.

Percolating beds, or what are called trickling filters in America, also came into vogue during the late nineties. They are the result of investigations by Corbett, at Salford, England, of means of distributing the liquid over coarse stones either from spray jets or from perforated traveling distributing pipes.

For many years no large contact beds have been installed, but the trickling filters have proven generally satisfactory for purifying clarified sewage and still remain the method for quite a number of large new undertakings, such as at Leeds and Bradford, England. They have been used quite generally for 20 years in the United States and serve a number of large cities, such as Baltimore, Columbus and Atlanta. Contact beds have the advantages of being more shallow and of requiring less head, but, for economic reasons, are seldom installed nowadays. It is mainly the trickling filters which now compete with activated sludge, the choice between these two types being dependent largely on relative costs and local conditions.

Chlorination.—Disinfection of sewage has been practiced for many years. German authorities require disinfection at sewage disposal plants where there are indications of infection of the sewage due to local epidemics. This type of treatment aims essentially at removal of objectionable bacteria. It has no relation to the removal of solid matters and ordinarily has little effect on the oxidation of dissolved organic matter. Beginning about 1913, the process has come into quite extensive use in the United States particularly for sewage discharged in proximity to water works intakes or shellfish layings. It is seldom used at sewage disposal plants in Europe. In practice chlorine is usually applied only to settled or clarified sewage. This is done partly to avoid wasting chlorine on the settleable solids and partly because the clarified sewage, being of more uniform quality, requires less variation in chlorine dosage. Chlorine is applied either as gas or as chloride of lime, the former being more frequently used.

Activated Sludge.—Research on this process dates from about 1912, but with one or two exceptions it was not until after the war that large plants were installed. This process has been adopted in a number of the largest recent undertakings and gives promise of being a suitable device, both as to cost and reliability,

for producing a well clarified effluent which will neither putrefy nor contain a large number of objectionable bacteria. This result is accomplished by aerating the sewage mixed with a sludge activated likewise by aeration to the point of becoming coated with bacterial life of oxidizing capacity.

BYPRODUCTS FROM SEWAGE

While there are some manufacturing wastes which yield byproducts showing a net profit for the undertaking, it has been and is a fact that municipal sewage, either with or without ordinary trade wastes, rarely, if ever, contains byproducts worthy of more than incidental consideration.

From earliest times there have been writers who have deplored the economic wastes incident to failure to employ the manurial properties of sewage. The expense of handling sewage in which domestic wastes are diluted a thousand times or more makes it impracticable to derive any profit from the use of sewage as fertilizer. This does not mean that there are no benefits attached to the manurial properties of sewage applied to cultivated land. Such benefits, however, compared with the total cost of sewage farming are a mere incident.

In arid regions there are some benefits to be derived from the use of sewage for purposes of irrigation, but even this is a far less promising proposition than would appear at first sight. This is associated partly with the clogging effect of sewage solids on the surface of the soil, thus making the irrigating value of sewage materially less than that of clean water. The principal drawback, however, is the difficulty and expense of disposing of the sewage in a hygienic and satisfactory way during the periods of rainfall when cultivated areas need no irrigation. In fact, the crop is materially handicapped when sewage is applied to land during rainy periods, especially during the harvesting season.

Some city sewages, such as at Bradford, England, contain a quantity of grease from wool-scouring or similar liquids so that there is substantial revenue derived from the sale of extracted grease.

Sludge or the sewage solid matters are frequently sold for a low price after drying. The cost is invariably more than the revenue obtained.

At Milwaukee, the activated sludge process produces an excess quantity of sludge containing colloidal and finely suspended

matters which are rich in plant food. The cost, however, of dewatering the sludge at present prices shows no net profit, although receipts from sludge sales will reduce the cost of the disposal works taken as a whole.

Since the World War consideration has been given in many places to the recovery of gas from the digestion of sludge and the indications are that it may be sold to gas companies or used under boilers or for operating combustion engines, so that there will be substantial income from sludge digestion.

Considering the question of sewage byproducts as a whole, it may be safely stated that there are no prospects of receipts equal to total cost of recovery. The problem resolves itself, therefore, into the sale of only those materials produced incidentally to efficient sewage treatment under local conditions.

STATUS OF PRESENT DISPOSAL METHODS

It is feasible to bring about practically any degree of purification sought, although obvious reasons of economy make it inadvisable to treat sewage with a greater thoroughness than is needed for local conditions. Entirely satisfactory results may be secured by adoption of one or more of the following arrangements:

1. Dilution with Proper Dispersion.—The dilution is aided by extending outfall sewers into deep water and, for large projects, by using multiple outlets to lessen the concentration of the sewage in the body of diluting water. This procedure has corrected the obvious pollution of many foreshores and has made unnecessary in some instances the adoption of artificial means of sewage treatment.

2. Clarification or Preliminary Treatment.—Good dispersion methods alone are often inadequate to prevent putrefaction or other objectionable conditions in the receiving water, and in many such cases clarification of the sewage provides a satisfactory remedy. Clarification is effected by sedimentation or, where a less complete removal of solids is required, by fine-screening. Both processes remove substantial portions of the organic solids and hence markedly lessen the burden on the assimilating powers of the water into which the effluent is discharged. Clarification is also used as preliminary treatment for the oxidation processes in which the finely divided or dissolved organic matters are removed.

3. Oxidizing Treatment.—Where streams are too small to receive without ensuing putrefaction a given volume of clarified dispersed sewage, it is entirely feasible, at reasonable cost, to remove organic matters by oxidation, either in bacteria beds or by the activated sludge process. Intermittent sand filters and contact beds have given good results, but, are now rarely adopted for new works. Satisfactory results may be secured by either the activated sludge method or by trickling filters, the choice depending upon local conditions.

4. Germicidal Treatment.—Where waterworks intakes or shellfish layings are involved, chlorination may be used to advantage and with less cost than oxidation treatments. Removal of from 90 to 95 per cent of the bacteria in raw sewage may be effected, however, by the activated sludge process and nearly as great a removal by trickling filters. Chlorination does not take the place of oxidation treatment in preventing putrefaction. Its disinfecting efficiency is impaired if it is applied to sewage containing coarse solid particles.

Summary.—It may be said that there are now available a limited number of sewage treatment methods as herein outlined which, in suitable combination, will meet practically every requirement for the disposal of sewage from ordinary cities and towns. This can be done at reasonable cost, although the expense will naturally vary materially under different local conditions. The main point to emphasize, however, is that practically any desired result may now be assured. There is no longer any excuse for continuance of the views of 25 to 75 years ago, when the lack of suitable methods prevented the remedying of many an objectionable case of stream pollution.

CHAPTER II

LEGAL AND LEGISLATIVE ASPECTS

Pollution of streams in various countries has given rise to much litigation and to still more discussion as to the practicability of litigation as a means of remedying sewage nuisances. There are two aspects to the legal side of the question. One relates to the common law and the other to statutory provisions. Each has an individuality for each particular locality. Hence it is not feasible nor wise to summarize custom and precedent with great particularity. However, the legal phases of sewage pollution may be outlined in a general fashion to facilitate a better understanding on the part of general readers. Detailed legal procedures in these problems are to be found in law books on water and in publications referred to in this volume. The common law and the statutory aspects of pollution are presented briefly below.

COMMON LAW

The common law interpretation controlling water pollution in Great Britain, the Canadian provinces and in many of the eastern states of the United States is well summarized by Lord Macnaghten in the case of Young v. Sankier Distillery Co. et al., decided by the British House of Lords in 1893 (Appeal cases, House of Lords and Judicial Committee of the Privy Council, 1893, p. 698):

A riparian proprietor is entitled to have the water of the stream, on the banks of which his property lies, flow down as it has been accustomed to flow down to his property, subject to the ordinary use of the flowing water by upper proprietors, and to such further use, if any, on their part in connection with their property as may be reasonable under the circumstances. Every riparian proprietor is thus entitled to the water of his stream, in its natural flow, without sensible diminution or increase and without sensible alteration in its character or quality. Any invasion of this right causing actual damage or calculated to found a claim which may ripen into an adverse right entitles the party injured to the intervention of the court.

These principles are generally applicable to municipal and other public authorities as well as to private corporations and individuals. Private rights, however, may be overridden by the acquisition of prescriptive rights, although the rights of the public cannot be overridden. Where riparian communities pollute streams they do so without exception in violation of the principles of the common law, in so far as that is applicable.

Authority to pollute non-tidal watercourses is procurable only by statute provision by prior appropriation, or in some cases by prescriptive rights acquired by 20 years' usage. With tidal waters, precedents are less definitely crystallized and are not yet on a moderately satisfactory basis. The reason is that the ownership of land on tidal waters does not confer upon the owner the right to have the ocean water brought to this property without contamination. Furthermore, in different states there is a different determination of private ownership with respect to low-water and high-water boundaries.

In the different states and provinces in America, precedents founded on the common law have been established with some degree of variation by the respective courts of final jurisdiction. This makes it imperative in considering the legal aspects of the problem to acquire a thorough understanding of the local circumstances, in view of the obvious desire of trial courts to render decisions in conformity with the decisions and precedents of the court above, to which appeal may be taken. It is sufficient to illustrate these possible differences by referring to the New England states where even prescriptive rights sanctioning the discharge of polluting matter into the streams, when it constitutes a nuisance, are not recognized in some states, as in Connecticut. In certain western and southern states the doctrine of prior appropriation is in force, while in others, more densely populated, prior appropriation is partly recognized.

There is a fundamental difference between the legal and the equitable remedies for stream pollution. It is first necessary to establish a nuisance. The question of damages then requires another proceeding. Consequently in equity each individual who seeks damages must proceed independently of associates who seek similar action against a common offender. Under the common law, water rights property cannot be taken for the use of the public except upon payment of an amount determined by condemnation proceedings authorized by statute or by private

negotiation. Until such rights of lower riparian owners have been acquired and paid for, municipal corporations are not permitted to pollute streams and hence are subject to the provision of the common law as are private corporations or individuals.

For further reference to leading decisions by courts of official jurisdiction in different states, the reader should consult Public Health Bulletin No. 87 of the U. S. Public Health Service (Treasury Department), on "Stream Pollution—A Digest of Judicial Decisions and a Compilation of Legislation Relating to the Subject," by Stanley D. Montgomery and Earle B. Phelps, November, 1917. In this summary interesting citations of cases will be found relating to stream pollution by industrial wastes, including mine drainage. Since the date of its appearance in 1917 a case of much significance in respect to mine drainage has been decided by the courts of last resort, with the result that the Sanderson case is no longer the guiding rule in Pennsylvania, which, with Indiana, was for years the only state not repudiating the principles laid down in the Sanderson case.[1] In this case, the supreme court of the state had held that the mine wastes discharge was permissible even though it rendered the water unfit for domestic purposes and caused other damage to lower riparian owners.

In closing this summary with respect to common law proceedings, it may be well to point out that much importance attaches to what may be termed the "reasonable use" of streams. Naturally this interpretation varies much under different circumstances as will be readily apparent to those who consult, in the above-mentioned bulletin, the digest of numerous cases in various states. A rule of reason is bound to apply and there has developed a growing tendency to recognize the interests of the public as controlling and paramount. Obviously, a balancing of equities and conveniences is essential to sound public policy in order to do justice to all concerned, thus making the whole question of common law procedure come within the practical rule of reason rather than a gesture towards complete elimination of pollution, a situation obviously impracticable no matter how desirable it may be from an academic standpoint. Difficulties with common law procedures have arisen at the start because of the large numbers of riparian owners affected, as well as the numbers of munici-

[1] Mountain Water Supply Co., Pennsylvania R. R. Co., et al. v. Melcroft Coal Co., et al., 1924, Sup. Ct. Pa.

pal corporations and others who pollute streams in densely populated areas. The plaintiff of today may be the defendant of tomorrow.

Experience has shown that the correction of stream pollution has not progressed anywhere to the extent necessary to provide fully satisfactory results. Its shortcomings in practice are related to the expense, trouble and annoyance of instituting legal proceedings to maintain riparian rights. In addition, those proposing legal proceedings at common law may be themselves frequently offenders and liable to proceedings by others, thus automatically restricting actions which ordinarily would be sought both by municipal and private corporations.

STATUTORY PROVISIONS

In all countries having areas densely populated and with small or moderate-sized watercourses, steps have been sought to reinforce control by common law proceedings through the enactment of statutory provisions. These are founded on the police powers of the enacting authority and are justified by the claim which citizens have on their government for protection of public health and welfare. There is no question as to the legality of such statutes if suitably phrased.

Speaking generally, statutory provisions in all the more civilized countries of the world have been passed when public opinion became sufficiently well crystallized to demand a remedy against unreasonable pollution.

Practically without exception, however, their limitations have taken the form not as to what the law provides, but what are the results which may be accomplished under the law and what are the administrative procedures, centralized or decentralized, by which the desired end may be attained.

Questions of policy are of much practical significance for those who have to deal with problems of this sort, and are summarized in Chapter III. A brief summary of the steps taken to provide suitable statutory control of pollution will be given here, beginning with the early efforts in England where these problems first arose and where the greatest attention has been given to administrative means for keeping pollution within the bounds of reason.

English Statutes against Pollution

English legislation prior to about 1850 seemed to be devoted largely to the minimizing of soil pollution near dwellings and the

abating of objectionable conditions in street drains, as these conditions were regarded as responsible for fevers and other diseases.

In 1847 Parliamentary acts gave local authorities power to discharge sewage directly to rivers or into the ocean. Sections 35 and 36 of the Town Improvement Clauses Act of that year specifically sanctioned the above procedure, while the Gas Works Clause Act, also 1847, forbade the discharge into rivers of substances produced in the making of gas and the Water Clauses Act, also 1847, gave the owners of waterworks certain powers to prevent pollution. In these documents it was pointed out that sewage might be utilized for the fertilization of land. Records indicate that by 1858 the pollution of rivers to the detriment and interests of others was legally prohibited. In 1861 an act was passed requiring sewage to be purified and freed from fecal and other putrescible matters prior to discharge into streams. In the same year, 1861, the Salmon Fisheries Act imposed penalties upon any person putting liquid or solid matter into a stream to an extent such as to poison or kill fish.

Those were the days when English rivers were in a wretched condition and such large cities as Birmingham, Huddersfield, Nottingham and Sheffield petitioned Parliament for the prohibition of the discharge of unpurified sewage into the local rivers. Deficiencies in knowledge as to how to solve the problems and the absence of adequate administrative authority permitted the English rivers to become worse and worse during an interval when several Royal Commissions made extensive inquiries into actual conditions of pollution and means for their remedy.

In 1876 the apparently efficient and, so far as legislation is concerned, adequate Rivers Pollution Prevention Act was passed. Had this measure been administered, it would unquestionably have solved pollution difficulties in a large measure, if not completely. The history of the pollution of English rivers from the date of this act will be dealt with in Chapter III.

American Statutory Provisions

The United States Government has no control of sewage disposal, except in so far as sewage deposits relate to the shoaling of navigable waters.[1] The Army engineers, under the Secretary of War, have immediate charge of navigable waters and have given

[1] Supplement to Revised U. S. Statutes, 1899, 2, 994.

consideration to questions of pollution upon request and with the approval of the Secretary. Apparently the legal status for this, other than as to deposits interfering with navigation, is predicated upon the ownership by the federal government of property in or near the waters in question. Certain investigations looking to the present and prospective pollution of interstate rivers, such as the Potomac, the Illinois and the Ohio, have been specially authorized by Congress and executed by the U. S. Public Health Service. Through its control of food sold in interstate commerce the Department of Agriculture has investigated and set up rules with respect to shellfish pollution, which subject has likewise been investigated by the U. S. Public Health Service. In cases of extensive pollution of interstate waters, such as the Chicago Drainage Canal and New York Harbor, the U. S. Supreme Court has accepted original jurisdiction and has passed upon the merits of injunction suits. In such cases the injunction proceedings have been brought in the name of a state with municipal and other parties in interest appearing as intervenors.

Beginning in 1886, when the State Board of Health in Massachusetts was reorganized, various states have enacted legislation to protect the purity of inland and tidal waters.[1] The reader of these statutes will be impressed with the variation which exists in different states and with the efforts made to fit legislation to local conditions and even to adjust to needs of local communities. Obviously such piecemeal development of statutory provisions is the result of public opinion becoming clearly crystallized as to the need of solving problems of certain types for certain localities. Those having to do with specific undertakings should make a special effort to become thoroughly familiar with the current statutes of the state or states in question.

Some reference should be made at this point to recent legislation passed in the state of Ohio, effective March 19, 1925, giving the State Department of Health the same control over industrial wastes that it already had over municipal wastes. It grants the Public Health Council power to make regulations designed to meet the varying needs of different rivers watersheds. This legislation will permit Ohio to zone the sources of its water supplies and to provide for their protection. The enactment further provides that new industries, whose waste products may pollute streams, and established industries wishing materially to

[1] United States Public Health Bulletin, No. 87, 1917.

increase or change the character of their wastes, must file plans of treatment that are satisfactory to the department. The purpose of this phase of the legislation was to protect unpolluted water supplies and to prevent an increase in those already polluted. In addition, the law permits the coordination of municipal and industrial effort by providing for the creation of districts in which graded and regulated control may be effectively carried out. The reader is referred to Appendix A for further details of this legislation.

Canadian statutory provisions relate to the precedents of England and the eastern states and require no comment here.

German Statutory Provisions

Each of the German states has its own legislative acts controlling river pollution. The constitution of the Reich does not readily permit the central government to supervise the pollution of interstate rivers, such as are many of the more important rivers in Germany. The Imperial Health Council under the Epidemic Diseases Act of June 30, 1900, does function, if necessary, but its endeavor is to secure active performance by local authorities. Consequently its position is passive, except in the instance of imminent danger from epidemics.

Prussia is more advanced in its legislation than the other German states. In 1901 it assumed supervisory authority over Prussian streams with a particular view to the prevention of disease and nuisance and the promotion of fish life. In that year Prussia established the Institute for Hygiene, which since that date has been maintained to supervise, from a hygienic standpoint, water supplies, sewage disposal and the pollution of soil and air. Its functions include the investigation of local conditions and available methods for remedial measures, advice to committees and cabinet officers in connection with the authorization of funds for the construction of purification works, as well as carrying forward a systematic program for the instruction of local medical and engineering authorities who have charge of arrangements relating to river pollution.

French Statutory Provisions

The pollution of the Seine reached most serious proportion some 50 years ago and the record of the resulting investigations and the installation of remedial works form an important contri-

bution on the control of pollution. The custom is for the French Parliament to issue specific laws for specific purposes. Thus, the arrangements for the collection of the Paris sewage and its delivery to irrigation farms was authorized by a series of laws up to July 1899, when the discharge of the sewers into the Seine ceased during dry weather. The consideration of later extensions was in each instance founded upon the passage of definite laws by the Chamber of Deputies and the Senate upon recommendation of the City of Paris and the support of the National Board of Public Works. All disposal projects in France have to meet the approval of the Superior Council of Public Health.

LEGAL ASPECTS OF ENGLISH EXPERIENCES WITH INDUSTRIAL WASTES

While the foregoing discussion relates primarily to sewage pollution as distinguished from industrial waste pollution, the latter is involved in the broad aspects of the problem and English efforts at statutory control of trade waste pollution are particularly interesting to persons responsible for public policies. In relating English experiences, we have made free use of Wilson and Calvert's text on "Trade Waste Waters."

Although the intolerable condition of English streams was due in some instances more to manufacturing wastes than to city sewage and although efforts to remedy sewage pollution dated from about 1847, public opinion did not sanction parliamentary action on pollution by trade wastes until 1876. It is true that acts restricting the discharge of gas house wastes were of early date and that various committees and commissions recognized that stream pollution was due in a large measure to manufacturing wastes.

Under the Rivers Pollution Prevention Act, 1876, the discharge of noxious, poisonous or polluting trade wastes, except mine drainage of natural character into streams, was prohibited unless the best practicable measures were taken to render harmless the wastes in question. Legal proceedings under the act could be taken only with the consent of the Local Government Board, which was practically given discretionary powers to decide whether manufacturers were using reasonable preventive measures. The act directed the Board to withhold consent to legal proceedings in any district that was the seat of any industry

unless satisfied that no material injury would be inflicted upon the industry in question.

The Act accomplished little in practical benefits. Trade wastes pollution, with a greater aggregate significance than that of city sewage, was universally practiced and the influence of the industrialists made it extremely difficult, if not impossible, to make a beginning.

Uncertainties as to remedial procedures, indefiniteness and inadequacy of the terms of the statute in respect to enforcing compliance therewith facilitated year after year a continuance, on the part of the manufacturer, of a policy of evasion and procrastination. Meantime conditions grew worse for reasons stated by Gaskell of the West Riding Rivers Board in an article in the *Nineteenth Century* in 1903: "The manufacturers were too powerful a body to be compelled to do their duty. 'Parliament,' I once said to Mr. Gladstone during the last year of his life, 'has been very lenient to the manufacturers.' 'Say far too cowardly,' replied Mr. Gladstone."

For some years after the 1876 Act was passed, accomplishments were slow and practically lacking until rivers boards were set up to deal with complete watersheds in some of the more densely populated districts of England, as will be briefly described in Chapter III under "Administration and Control." It is difficult to understand at this date how great was the retarding influence of the 1876 Act because it strove for such perfection that compliance with its terms involved the requirements of land treatment for mixed town and trade wastes, according to the Local Government Board having general jurisdiction over stream pollution. No doubt the reports of earlier Royal Commissions on Sewage Disposal made such a position technically sound regardless of its impracticability. With the advent of biological processes public opinion led to the appointment in 1898 of a Royal Commission which made its final report in 1915. Several interim reports were issued dealing with the particulars of many aspects of the trade wastes situation. In their third (1903) report they recorded their position as follows:

> . . . that sewage containing trade effluents is generally more difficult to purify than ordinary sewage . . . Our results fully support the view that it is practicable in the great majority of cases to purify mixtures of sewage and trade effluents if the manufacturers adopt reasonable preliminary measures . . . We are satisfied that in some

cases at least the purification of the trade effluent by itself would be very difficult to accomplish . . . We are therefore of opinion that the law should be altered so as to make it the duty of the local authority to provide such sewers as are necessary to carry trade effluents as well as domestic sewage, and that the manufacturer should be given the right, subject to the observance of certain safeguards, to discharge trade effluents into the sewers.

While subsequent reports threw much light upon detailed processes or procedures, the advent of the war no doubt was a material factor in the comparative absence of progress in handling the trade waste question. While much has been done by the rivers boards, the recommendations of the Commission concerning the establishment of a central authority and other administrative procedures have not been enacted into law. Neither have the financial aspects as between municipalities and manufacturers been adequately dealt with. We shall touch upon these subjects under their respective headings. In the meantime it is to be recorded that trade wastes in England so far as the central government is concerned are dealt with in accordance with certain sections of the Public Health Act, 1875, the Rivers Pollution Prevention Act, 1876, and the Public Health Acts Amendment, 1890. Under these sections local authorities are required to provide sewer facilities to carry local trade wastes, except such as are harmful to sewers or to treatment processes and unless compliance means overtaxing of sewers or interference with an order of a court of jurisdiction.

The 1890 Act prohibits the discharge into the sewers or storm drains of a local authority, of substances interfering with the flow or injurious to the sewer, and prohibits particularly chemical refuse, waste steam, hot water or liquids above 110° F. such as to cause nuisance or injure health. This Act must be adopted by a Sanitary Authority before it becomes operative within their district.

While at first sight the above law seems sufficiently clear, repeated instances of expensive litigation have shown its inadequacy and the visitor to England gathers the impression that actual accomplishments, which exceed those in any other country, are due mainly to a tactful molding of public opinion and friendly guidance of the manufacturers.

CHAPTER III

ADMINISTRATIVE ASPECTS

When sewage disposal problems occur, there are obviously many directions in which administrative authority may function. With similar problems confronting officials, administrative programs differ in different situations and in different countries. To meet the variety of problems occurring, many forms of administrative agencies have been set up to harmonize with local laws, psychology, finances, politics and personnel. A review of some of these types of organization and method should be of aid in formulating many programs of action. Foreign and American practice, federal, state and municipal authority, or combinations thereof in voluntary or compulsory form, are here set forth briefly as records of some administrative needs and performances.

ENGLISH EXPERIENCES

England, the home of sanitary engineering, has contributed the most progress to matters of administration and control of stream pollution. On the recommendation of the Royal Commission on Sewage Disposal there was established in 1871 the Local Government Board which was the central authority of England for the supervision of sewage disposal matters. Its duties were taken over by the Ministry of Health in 1918. An outstanding feature of English practice was the Public Health Act of 1875 stipulating that the Local Government Board should sanction loans for purposes of sewage disposal only after the schemes had been favorably reported upon by an inspector of that Board following a local inquiry. This Board adhered closely to the recommendations of earlier commissions that land treatment should be required in practically all cases. Unwittingly the high standard of the 1876 Rivers Pollution Prevention Act and the administrative policy of the Local Government Board as to land treatment did a great deal to restrict the practical accomplishments with sewage disposal in England.

Another factor making the 1876 Act practically a dead letter for many years was that local administration was entrusted to the care of a multiplicity of local sanitary authorities, nearly all of whom represented political units that were gross offenders as to river pollution. Improvements followed the establishment of County Councils by the 1888 Act. As the Councils' jurisdictions covered large areas, they were in a much better position to function as they were not officially contributors themselves to local pollution.

Rivers Boards

Probably the greatest step of all was the provision in the 1888 Act for the establishment of river boards having jurisdiction under the Local Government over all matters of pollution by sewage and trade wastes in given areas. Under this act three important Rivers Boards were established; for the Mersey and Irwell, the West Riding of Yorkshire and the Ribble.

These river boards with jurisdiction over entire watersheds with respect both to town sewage and trade wastes account for a large portion of accomplishments in the British field of sewage disposal. It is true that they had the advantage of improved processes for remedial treatment with the bacterial methods. That they are entitled to great credit is shown by the extent to which they have brought about treatment works in their respective areas.

West Riding of Yorkshire.—In the West Riding of Yorkshire, for example, the number of sewage works in operation during successive periods of its history are given by Wilson, Chief Inspector, as follows:

Works in	1895–6	1910–1	1921–2	1922–3	1923–4	1924–5	1925–6
operation	167	390	415	415	419	417	413

Of these 413 works the great majority have treatment by tanks, percolating filters and humus tanks or land. In 119 cases treatment is by tanks and land, or sometimes by irrigation without tanks, but these are cases of small communities in country districts. Although there are 15 instances where contact beds are in use, no new contact beds are being constructed.

In 1926, the activated sludge method was used by 6 authorities, with 3 other plants under construction.

Ribble.—Halliwell, Chief Inspector for the Ribble Joint Committee, indicates in personal communication in 1926 that practically all the County Boroughs, Municipal Boroughs, Urban District Councils and most of the Rural District Councils have sewage works capable of efficiently purifying the dry weather flow of sewage. In no case are polarite or sand filters, or contact beds being extended. Percolating beds or trickling filters are replacing the sand filters and contact beds in many cases. Treatment by activated sludge has made little headway, although a plant dealing with a dry weather flow of 200,000 gallons was at work at Nelson in 1926 and the Burnley Corporation was considering (1926) the replacement of contact beds with the activated sludge process.

Mersey and Irwell.—In the Mersey and Irwell watershed 133 sewage disposal works were operated in 1926 by 89 Local Authorities, according to Stowell, Chief Inspector of the Rivers Mersey and Irwell Joint Committee. It is especially striking that in 1926 only one Local Authority had no sewage works, and there no pollution of rivers had occurred. In the same year 381 trades wastes treatment plants were in operation and 750 trade effluents were discharged directly into public sewers, with efficient disposal.

These river boards are composed of representatives from the councils of various interested cities, boroughs and counties. Manufacturers have no direct representation, except in so far as members of their group elected to some council are then in turn chosen as local representatives on the joint river boards.

There are other much older conservancy boards dealing with the Thames and the Lea from which London draws the greater portion of its water supply.

Boards dealing with an entire watershed have proven a far greater administrative success than the central governmental authority or the local authorities, themselves associated with pollution situations, or than combinations of the central board with either county or local boards. The river boards enjoy the confidence alike of town authorities and manufacturers, and they have had sufficient contact with the central government to effect reasonable coordination of program. Perhaps these latter statements should be tempered by the fact that the Local Govern-

ment Board after its slavish devotion to land treatment, had its views modified as to biological and physical treatment through subsequent reports of the Royal Commissions.

Central Authority Recommended

The administrative views of the Royal Commission (Third Report, 1903), favored by the Local Government Board for adoption prior to the World War, are worth summarizing. This Commission advised the creation, throughout the country, of Rivers Boards, each to deal with pollution matters over an entire watershed or a large district and each to have jurisdiction in certain particulars over the various Local Authorities therein. They recommended that the Central Authority should exercise general superintendence over the whole country as to prevention of pollution, and should direct investigations as needed and generally stimulate the proposed Rivers Boards. Other important features of the Royal Commissions recommendations and findings are briefly as follows:

(*a*) The Local Authorities should be required in general to provide sewers to carry trade effluents as well as domestic sewage, subject to certain regulations to be framed by each Local Authority and confirmed by a Central Authority.

(*b*) Wherever practicable, needed preliminary treatment should be carried out by the manufacturer at his expense.

(*c*) The Local Authority should be empowered to provide, where necessary or desirable, a separate sewer for trade refuse, works for the partial treatment of refuse prior to final treatment with sewage, and means for the disposal of trade sludge, the latter at the expense of the manufacturer.

(*d*) The Local Authority should be empowered to make special charges to a manufacturer where circumstances are exceptional as to volume or quality of his waste or otherwise, but ordinarily should make no special charge if the manufacturer complies with regulations as to preliminary treatment.

(*e*) All manufacturers should be on the same footing, including those served by sewers and those proposing a connection.

(*f*) The manufacturer should not be relieved by statute of his obligation to return to a stream water taken therefrom by him, and while he may discharge such water to a sewer of a Local Authority he alone is responsible for possible infringement of riparian rights of others along the stream.

(*g*) Differences between manufacturers and Local Authorities should be determined in general by the Rivers Boards, and particularly in the cases of disputes as to amount of special charge, removal of sludge, modification for special problems of general regulations regarding preliminary treatment and cases of fact as to whether the treatment adopted by the particular manufacturer complies with regulations; either party to have the right to appeal to the Central Authority.

(*h*) The Central Authority alone should deal with cases of refusal of a Local Authority to allow a particular trade effluent to enter their sewers, or to enlarge or construct sewers for the purpose of a particular manufactory.

Although intervention of the war and lack of crystallization of public opinion since the war have prevented the enactment of these recommendations into law, it is a fact that several cities have secured acts to proceed in accordance with the recommendations of the Commission and real progress is being made in coordinating financial arrangements with a view to advancing the solution of the disposal of town sewage and trade wastes.

German Practice

Probably the greatest weakness of the laws under which rivers boards of England are created is that the manufacturers have no direct representation on the administrative boards. This has been corrected in Germany in the Emscher Drainage District where accomplishments have been very substantial as set forth in the 1925 report of its "25 Years of Operation." Under the terms of the Prussian Law of 1904, the Emscher Genossenschaft was established to regulate the river Emscher and its tributaries as well as to treat the sewage and trade wastes of the District. The members are the counties, the taxpayers who have to pay the annual costs and the cities and big factories and coal mines of the District. The Genossenschaft has the right to build and operate plants and to issue bonds. The yearly expenses for interest, sinking fund, operation and maintenance of the plants are collected from the participants by taxes.

The Ruhrverband was established under the Prussian Law of June 1913 for the purpose of cleaning up the Ruhr and its tributaries. Its members are the cities, the large factories, the coal mines and the waterworks which latter are combined into the Ruhr Waterworks Corporation. The members have a voting

right in proportion to the amount of money which they are called upon to pay. The majority control is in the hands of municipalities and not of the manufacturers. The Ruhrverband constructs intercepting sewers, pumping stations, purification works and devices for treating trade wastes.

American Practice

In America it has already been explained what the statutes provide in respect to federal and state jurisdiction. In the different states the control varies somewhat. Massachusetts, the first state to take up the sewage problem, follows closely the English precedents. In Massachusetts, as well as in England, larger cities can secure by legislative act authorization for issuing bonds to defray construction costs. In the absence of such special acts it is necessary to secure the approval of the Massachusetts State Health Department, as is the case in England with the Ministry of Health. Without a special act and without the sanction of the health authority, sewage disposal expenditures must come from local taxation or from surplus funds in the hands of the Treasury. In states other than Massachusetts practice varies, but in many of the states it is not legal for a city or town to let a contract for building sewage works unless plans have first been approved by the state health authority. This is not as strong as the English or Massachusetts provision, but it is generally respected, because according to prevailing views, in the absence of such approval a taxpayer's injunction suit would quickly and readily stop the execution of a contract.

Sewerage districts, such as the Metropolitan District in Massachusetts, Passaic Valley Sewerage District in New Jersey, Sanitary District of Chicago in Illinois and many smaller ones, have been authorized by special acts of the Legislature. In quite a number of the states there are general laws permitting the formation of sewerage districts under specified procedures which necessarily differ in the different states according to provisions of their respective constitutions. Interesting detailed data on these matters have been published by Pearse, Earl and Reppert in American Society for Municipal Improvements, Proc. 1921, p. 109.

In the United States, remedying of stream pollution caused by industrial wastes is more difficult, if anything, than that of remedying sewage pollution. The authority of state health

departments is less definite and in some instances their jurisdiction is subject to specific exemptions as to certain types of industrial wastes. For example, the State Department of Health of Pennsylvania until recently had no jurisdiction over tannery wastes or mine drainage.

While many manufacturing establishments treat their wastes more or less completely before discharging them into watercourses or public sewers, their general attitude has been one of procrastination and inaction, except in instances where riparian owners have brought suit to enjoin continuance of pollution. In some cases the recovery of byproducts has paid for treatment, but even in such instances the initial steps have been taken with reluctance by the owners of industrial plants.

Some of this inertia may be explained by the fact that large manufactories have been built piecemeal, and their drainage facilities provide no convenient arrangement for separating slightly polluted waters, which might readily go untreated to a stream, from those which should be treated.

Generally speaking, betterments at manufactories lag through the procrastination which comes from inadequate or dilatory steps by public authorities in handling their own sewage problems. Usually industrial wastes are disposed of directly into the streams where that is feasible, although there are many establishments where the discharge goes directly into the public sewers. Little progress has been made in America in collecting from manufacturers allocated payment for service rendered in the treatment of wastes. It has been difficult enough for the authorities to secure cooperation in the elimination of acid, tar and other products which tend to disintegrate sewers and seriously to complicate treatment processes. As the years go by, however, it is discernible that manufacturers are making some response to requests of this nature and also in the matter of giving their wastes some preliminary treatment where necessary and of releasing them into the sewers in such a manner as not needlessly to increase peak rates of flow in the public sewers.

In recent years considerable progress has been made in bringing about cooperation of industry in the gradual solution of industrial wastes problems. Methods of administrative control and forms of legislation have not been thoroughly standardized in this country, and there are probably many reasons inherent in the variations of problems why it would not be particularly desirable

to do so. There are several instances, however, in which the problems have been attacked and initial steps towards solution inaugurated which deserve brief mention at this point.

The Pennsylvania Sanitary Water Board.—In Pennsylvania, for example, the creation of the Sanitary Water Board in the Department of Health through the Administrative Code of June 7, 1923, offers an interesting example of the effort to formulate improved administrative methods of regulating pollution of streams. The Sanitary Water Board is vested with jurisdiction over the pollutions of the waters of the state. The Board consists of the Secretary of Health, as Chairman, the Secretary of Forests and Waters, the Commissioner of Fisheries, the Chairman of the Public Service Commission and the Attorney-General. These same state officials, with the exception of the Attorney-General, are also members of the Water and Power Resources Board, which has authority over other matters relating to the waters of the state.

The Sanitary Water Board administers the provisions, as far as sewerage is concerned, of the so called "Purity of Waters Act," of the anti-pollution portion of the Fish Law of 1917 and the provisions of the Act of July 14, 1923. In other words, the Sanitary Water Board authorizes the issuance of sewerage permits approving plans of sewers and sewage treatment works and stipulating conditions under which sewage may be discharged pursuant to the "Purities of Waters Act." This Board has classified the waters of the state of Pennsylvania into three major classes, (*a*) of relatively clean and pure streams, (*b*) streams in which pollution shall be controlled and (*c*) streams which are now so polluted that they cannot be used as sources of public water supplies, and where restoration of cleanly conditions is not thought necessary, economical or advisable.

In the execution of its powers, the Sanitary Water Board has instituted negotiations with various groups of major industries in the state and has so far been quite successful in the development of committees for research and betterment of stream conditions.

Ohio Program.—Similar progress has been made in the state of Ohio through entirely different legal auspices by vesting in the State Department of Health itself sufficient powers by new legislation to control industrial wastes pollution. The form of legislation in this case has already been set forth in Chapter II

and Appendix A. Ohio has undertaken, under the direction of its Health Commissioner, Dr. John E. Monger, cooperation with a large number of industries with promise of considerable success.

Interstate Agreements.—Owing to the peculiar regional character of the problems involved in many of the rivers, voluntary interstate compacts have already had significant discussion. Such interstate agreements[1] on the control and regulation of pollution of interstate streams have already been accomplished in the cases of Pennsylvania, Ohio, West Virginia, Kentucky and New York. They are under discussion at this writing in the states of Indiana, Illinois and Michigan and in connection with the joint problems of Pennsylvania, Maryland and West Virginia. Minnesota and Wisconsin are formulating (1926) a joint agreement for the investigation of the Mississippi River at Minneapolis. There is much promise in such efforts of individual states to meet interstate difficulties by joint agreements. Apparently there is not much optimism about the desirability or the necessity of having even general federal legislation on these interstate problems. Most of the states would prefer to test out interstate agreement rather than to be subject to federal legislation, which would necessarily have to be drastic in order to be effective.

State Conferences on Phenol Wastes.—In as much as most of the plans indicated above for control of industrial wastes are largely dependent upon cooperation of industry and education of the public in general, the efforts of a group of states to determine upon a solution of a particular wastes situation, in consultation with the groups of industries affected, deserve reference here. A number of states along the Ohio River effected, through conference in Washington, an organization of health departments for the purpose of working out a solution to the problem of phenol wastes. This group has had several meetings with representatives of all the coke plants operating along the streams entering the Ohio River and have reached an agreement for treatment of wastes discharged into water supplies used for public purposes. As a result of these sessions and of interstate compacts, the state of Pennsylvania has been able to show 80 per cent correction of phenol pollution and a pledge that 20 per

[1] The reader is referred to the Transactions of the Sixth Conference of State Sanitary Engineers, 1925, Pub. Health Bull. No. 160, U. S. Public Health Service, for details of these interstate agreements. See Appendix B.

cent would be cared for within a year. West Virginia has made substantial progress and Ohio shows the elimination of perhaps 50 per cent of offenders, with the other half in process of elimination.

International Conference on Oil Pollution.—Efforts at international agreement on problems of pollution have culminated in the Conference on Oil Pollution of Navigable Waters which began its sessions in Washington on June 8, 1926. This is one of the first examples of where international efforts have become necessary in order to curb pollution extending from one country to another because of discharge of oils from sea-going vessels. The conference has tentatively agreed that the various governments should take steps to prevent the discharge of oil from ships within prescribed areas along the coasts and that the breadth of such areas shall not exceed 50 miles from the coasts, except where necessity warrants, when this shall be extended to a maximum of 150 miles, after appropriate consultation with neighboring governments.

All of the undertakings briefly presented above indicate without exception that the missing link in the most effective control of industrial wastes is probably not so much the absence of powerful laws as the failure of the public in general and industry in particular to realize the conditions resulting from haphazard disposal of materials into adjacent watercourses. Legislation, without an enlightened public opinion, is not likely to be the solution. The necessity and importance of the general problem must be emphasized and re-emphasized. Few people are yet fully aware of the damages to health and welfare, to fish life and recreation, which unregulated pollution brings in its wake. Police power rarely develops a civic and industrial conscience. To combat intelligently and actively indiscriminate destruction of a great public asset in our streams and to develop economic and practicable methods to meet the problems requires understanding, sympathy and cooperation. The law may prohibit the infringement, but understanding directs the elimination or the prevention, of the objectionable act.

Summary

Generally speaking, the administration and control of procedures for remedying the sewage problem have gradually progressed after various initial difficulties which are well worthy of study on the part of those who must consider problems of this

type. One precedent for thickly populated areas where there is much manufacturing is to be found in Westphalia where the manufacturers have been given direct representation on the district boards. Perhaps the river boards of England have proceeded as well under their law as would have been the case under the Emscher or Ruhr district laws.

The programs of the states of Pennsylvania, Ohio, Wisconsin, Maryland, West Virginia and others, which are seeking joint action with industry, with or without drastic laws, appear to be productive of excellent results.

It is believed, however, that manufacturers who contribute substantially to the expense should have a voice in the manner in which their money is being spent and that it should be accorded them by direct representation rather than by the indirect English method of having to secure, first, a place on the local council for the manufacturers' representative and then his selection on to a rivers board. Whether this is wholly practicable in the United States is debatable. Such participation of industry in this country is likely to be of a voluntary extra-legal character. The strength of such agreements would be dependent largely upon local conditions.

Management of Plant Operation

No matter how competent an engineer may be in the design and construction of sewage treatment works, the expected benefits will not be attained unless the works are operated in an efficient, economical way.

Speaking generally, the sewage works of large cities both in America and Europe, particularly in England, are well managed. Laboratory facilities fill the needs for testing and recording the efficiency of treatment and registering devices show the quantities treated.

At most large plants cost data are kept with substantial accuracy and it is interesting to note that the powerful and much respected Sewage Works Managers Association of England is about to adopt a standard form of accounting.

In America, sewage works of small cities and towns are often poorly managed. The personnel at the works is ignorant of the principles involved and frequently there is only random attention from a superintendent of streets, who uses his men at the sewage works when they are not needed elsewhere. After

public funds have been expended for sewage works it is folly to defeat their purpose by mis-operation or neglect which explains largely the poor reputation in some sections of the country of sewage treatment works in general and certain types in particular.

Some state health departments, having funds available, make every effort to secure efficient management of sewage disposal plants. Poor operation is largely a result of indifference on the part of city and town officials and of complete lack of interest by civic organizations and citizens. Its correction lies in the development of an intelligent public opinion founded upon a knowledge of the principal facts as to this branch of municipal sanitation.

American sewage works, with incidental or no revenue, are frequently operated so poorly in comparison with water or electric plants that there is a growing movement for putting their management in the hands of only those registered or certified managers who produce satisfactory evidence to the state authorities that they are competent to manage the works in question. The benefits of good management undoubtedly exceed its cost, in that it brings about a substantial fulfillment of the object sought when the works were installed. Without good management there is waste of capital, as is obvious to those who inspect the dilapidated and neglected sewage disposal works so frequently found in the United States.

Another benefit coming from efficient management is the keeping of adequate operating records which are the backbone of efficient design for extensions of old and the construction of new plants. While research is a term more generally applied to collection of small scale data, particularly those secured in the laboratory, yet it is a fact that the designing engineer is more keenly interested in the results of research such as are found in the operating records of a well managed sewage disposal plant. Such records also protect the authorities in charge of many a sewage treatment plant from riparian owners' suits and other complications, particularly where streams are polluted from more than one source. It is not too strong a statement to say that every competent supervisory authority is, and of necessity must be, a strong supporter of efficient management and is at all times willing to testify to the wisdom of good management as against bad management in the arrangements provided for the protection of the purity of inland waters.

FINANCIAL CONSIDERATIONS

Costs vary greatly for outfall sewers, pumping stations, force mains, land and treatment works, because of the differences in local conditions. Where the conditions to be remedied are so bad as to have the support of public opinion or where remedial works are installed under court orders, it is not difficult to secure needed funds, especially in the early life of a works. But when works are founded only on a determination of a local authority to provide cleanliness of watercourses and to correct nuisances affecting only a few in the town whose sewage is to be treated, the situation assumes a materially different aspect.

Those securing financial support for sewage disposal projects must compete with other local officials in charge of other facilities and are embarrassed by the fact that sewage projects mean expense with little or no income. Hence it is frequently difficult to finance sewage works in the face of demands made by the same community for water supply, electric works, parks, schools, hospitals, streets, roads, and the like. Such a situation generally taxes to the utmost the ingenuity of those who must secure funds for reasonably solving the sewage problem. Furthermore, it will continue to prevail until a more intelligent public opinion is aroused in the interests of public health and welfare, as these are related to suitable cleanliness of neighboring watercourses.

From what has been said it is apparent that industrial wastes frequently add serious complications to the sewage problem. In some instances their disposal involves substantial expense beyond what would be required for domestic and commercial sewage alone. In the 50 years since the passage of the Rivers Pollution Prevention Act in England, the manufacturers, generally speaking, have proceeded with extreme slowness in doing their share towards solving the sewage problem, although there are marked exceptions in certain densely populated valleys subject to the control of river boards. As a rule adequate waste disposal has meant a burden on the local taxpayers rather than on the manufacturers who should treat industrial wastes at the point of origin or play a reasonably cooperative part in separating those wastes requiring treatment from those which reasonably might be discharged into a watercourse. The same statement applies to tanks for equalizing the flow into the sewers, as well as to the removal of solid matters, of acid or other compounds which would corrode the sewer or cause dangerous explosions. Here, too, is a

situation which requires for its solution the support of an intelligent, unified public opinion, even in the case where local boards are established with reasonable representation of the views of manufacturers.

A hopeful feature in the problem of financial arrangements is the progress being made in some cases in England where contracts are being made between the municipalities and manufacturers, whereby industrial wastes are received into municipal sewers and treatment works at stipulated prices. (See Appendix A.) Some mills in the Bradford district pay as much as 8 pence a thousand gallons for such service. The city of Bradford itself is now engaged in litigation to adjudicate financial aspects along the lines herein indicated. This litigation also involves the important question as to whether wool-scouring plants may treat their own wastes at periods when they can do so with profit and, during the remainder of the time, send their wastes to the municipal works, thus upsetting its regimen of operation and particularly its budget, both as to operating costs and operating revenues.

POLICY PROBLEMS

The solution of the sewage problem has been retarded by the existence of various and varying policies as against a unified continuing policy. Perhaps it would have been better in some localities if progress had been retarded by the absence of any definite policy, which sometimes has added to rather than lessened the difficulties of advancement. Policies have become stabilized, however, in some places and in some particulars.

In the New England states there are a few rivers, particularly the interstate streams, like the Merrimac and the Connecticut rivers, and others like the Naugatuck in densely, built-up manufacturing districts, where sewage pollution has received comparatively little attention. Generally speaking, however, the rivers in New England have been maintained on a reasonable basis as to purity. The solution of disposal problems has been facilitated by the existence of glacial drift formations having porous sand beds suitable for intermittent sand filtration. Another factor has been the policy of the Metropolitan Water Board, whereby sewage was purified at the expense of the Boston District with a view to protecting the quality of the Metropolitan supply, still used from large storage reservoirs without filtration. A similar

policy has prevailed for 20 years or more with respect to the water supply of New York City, both in the Croton and Catskill watersheds.

While there has been a widespread and extensive development in the United States in the filtration of its public water supplies during the past 25 years, many supplies from surface sources are still used without filtration. This fact and the desirability, quite generally recognized, of minimizing the bacterial load to which filter plants, particularly of the rapid type, are subjected, has led since 1910 to the general practice in America of considering sewage effluents in the light of their bacterial composition. Hence there has developed the frequent practice of chlorinating sewage effluents after various degrees of clarification and purification. About 400 sewage chlorination plants are said to be now in service in the United States. Concerning application to effluents of the activated sludge process as installed, for example, at Milwaukee, it is likely that chlorination may be restricted to emergency uses if used at all.

There are fish commissioners in most of the states and provinces in America, as well as in European countries. Frequently they have much legal authority, but are rarely equipped to assert it. Nevertheless they have considerable opportunity to formulate public opinion as to steps which should be taken to protect major fish life. In the United States, where there is rarely if ever serious lack of food supply, their discussions may have been received in a more or less academic fashion. However, within the past few years there have sprung up over large areas of the country many branches of what is termed the "Izaak Walton League." Its purpose is to oppose the continued pollution of American rivers and various talks of its members over the radio have no doubt had much to do, in some places, in bringing support to the policy to which they subscribe. The League stands for less polluted rivers, because of the fact that major fish life demands that a stream be not only free from poisonous substances, but that it be sufficiently free from putrescible organic matter so that no serious depletion in dissolved oxygen will result.

It is interesting to note that in London some consideration is being given to the purification of the lower Thames to the extent needed to restore fish life in those reaches where there now is none and where in earlier years salmon abounded. A sound decision is largely a question of whether the game is worth the candle.

This instance is cited as illustrating one of the varying viewpoints now so characteristic of attempts at settling the sewage problem.

EDUCATIONAL ASPECTS

Students of municipal sanitation can hardly fail to be impressed with the wide variations in statutory provisions relating to the sewage problem, as well as with the diversity of policies and difficulties in matters of financing, administering and managing projects. The very nature of the waste product makes it a difficult subject upon which to enlist support for needed authorization in comparison with the authorization for other branches of the utility field, which either have direct revenue-producing capacity or else serve needs more readily apparent to the lay mind.

For years there has been a shuffling around in various parts of the world in methods of endeavor for bettering the status of the sewage problem. There has always been one group which has sought to bring about ideal conditions with complete purification, while the majority of those in administrative control have been generally inclined to let matters drift along with a minimum effort and to apply available funds to more attractive undertakings.

But the time has come when the middle-of-the-road policy is not only wisest, but seems essential, if the sewage problem is to receive the attention which it deserves in the interests of public health and welfare.

Public officials will generally act affirmatively on undertakings which receive adequate support from public opinion. Support can be secured only as a result of systematic efforts to educate the public to the significance of the sewage problem. Civic and other organizations are not difficult to approach and in many localities it seems urgent that those appreciative of what the sewage problem means should make unusual effort to pursue along educational lines such steps as are needed to bring about the support requisite for authorization.

Regional and local authorities, of course, have an important part to play, but real progress seems to call for the education of such portion of the citizenry as is needed to get an undertaking actually under way. Many states are carrying forward such programs of education as an administrative policy. The operations in Pennsylvania, under Miner and Stevenson; in Ohio, under Monger and Dittoe; in Maryland, under Fulton and

Wolman; in West Virginia, under Henshaw and Tisdale, and in an ever-increasing group of states, such as Texas, Wisconsin and Illinois, exemplify the policy of cooperation and education as against that of law and police power.

NECESSITY FOR COMPREHENSIVE REGIONAL PROGRAMS

It cannot be overemphasized, in addition, that with the growth of American communities in the last few decades, new and more extensive problems in planning have arisen which did not confront us years ago. Future sewerage systems and disposal facilities cannot be planned only on the basis of existing political boundaries. Such plans now assume regional aspects in which future expanded boundaries with consequent population saturations are controlling factors. Viewing population centers from a broader angle will result in great economy of all programs of the character here discussed.

With all possible foresight in planning, however, the amazing growth of American municipalities demands eternal vigilance in keeping facilities abreast of requirements under the new and more exacting standards. This is fundamentally true of collecting arrangements, such as sewage interceptors. Not infrequently, rapidly expanding urban areas have their drainage unloaded onto outgrown collecting units, with the resulting spill of raw sewage into small waterways. Especially deplorable is the consequent gross pollution, when these small streams feature park developments that are the playground of city masses. The fine modern trend toward liberal civic expenditures for parks and parkways, to conserve the natural beauty of stream valleys, finds the sewage problem chief among its difficulties. There is occasional unwillingness on the part of sewerage officials to correct such abuses, although they expend great sums in extending systems which tend to aggravate these same conditions.

While it is undoubtedly true that local authorities need prodding before they will face an adequate solution of many a sewage problem, yet it is to be pointed out that such solution does not necessarily mean the installation at one time of the entire improvement program. The project should be studied and a comprehensive program planned for serving many years in advance. The needed construction may then be built piecemeal as funds are made available. In this way a well coordinated undertaking may be secured at a reasonable cost.

CHAPTER IV

CHARACTERISTCIS OF SEWAGE[1]

SYNOPSIS

1. Variable Composition.—Although there is a substantial constancy in certain basic data, it is characteristic of the sewages of various cities that they differ much in quantity and quality. The major causes of varying strength are differences in volume of diluting water and the influence of street wash and industrial wastes.

2. Household Wastes.—These wastes in grams or pounds per capita daily are fairly constant on an average, although no doubt subject to variations due to seasons, habits, localities, etc. For many years this population basis has been the starting point of safe estimates of the strength of sewage.

3. Hourly Variation.—The flow of separate sewers in residential towns may show a range from 180 to 40, expressed in percentages of daily averages as representing differences between mid-day and late night water consumption. Variations in wastes entering the sewers and the degree of their dilution cause the strength of the sewage to vary still more as it flows in fairly small sewers, although at the outfall of large city sewers the increasing time in transit lessens the departures from average strength.

4. Roof Leaders.—Where there are separate sewers for domestic wastes (as distinguished from combined sewers for these wastes and storm water) the flow of sewage frequently shows wide fluctuations due to roof water discharged into sewers in violation of regulations.

5. Cesspools.—In some localities, particularly in Europe, cesspools are retained in use, so that it is only the overflow which reaches the sewers. This materially lessens the quantity and the nature of solids suspended in the flow of the sewers.

6. Single Samples Misleading.—Single samples or a number taken at random may afford analytical data quite unrepresenta-

[1] The discussions presented in this Chapter should be considered supplementary to similar data already presented in Chapter I.

tive or misleading for estimating the load which the sewage flow will impose on a disposal project.

7. Representative Data Needed.—The basic data on which a sewage disposal project should be founded should be representative, therefore, of the volume and strength of sewage at a given future date and not related to random laboratory data or flow measurements of current date.

8. Combined Sewer Flows.—These show the characteristics of the flow of separate sewers, as above outlined, plus the influence of street wash during rains, which for 3 to 5 per cent of the time in much of the area of the United States add greatly to the volume of and influence the quality of flow. In earlier years, data at many places showed combined sewers on an average to yield 40 to 50 per cent more suspended matter and organic matter than separate sewers. With the advent of more motor vehicles and of hard-surfaced roads in and near the towns this difference is becoming less.

9. Fats and Oils.—These items need more attention than formerly due to the increased use of motor vehicles and of fuel oil. As a result they affect watercourses and quality of sewage, regardless of restricting regulations.

10. Industrial Wastes.—At some localities these are of more significance than household wastes entering the sewers. They need careful study at the point of origin as to volume and composition, as well as to the effect resulting from mixtures in the sewers.

11. Comminution.—At the outfall of small sewer systems the suspended solids are usually not broken up, while at large works they are so comminuted as to cause somewhat different behavior as to subsidence and removal by screening or other devices. Increasing age of sewage also causes decreasing freshness, as the dissolved oxygen of the liquid decreases with the bacterial decomposition of organic matter.

12. Temperature.—Various biological activities associated with the sewage decomposition thrive more with warm than cold temperatures. Hence the temperature records of the sewage are important.

13. Laboratory Methods.—These should be unified so far as practicable. This can be well done by following "Standard Methods for the Examination of Water and Sewage."[1]

[1] Sixth Edition, 1925, prepared jointly by the American Public Health Association and the American Water Works Association.

VARYING STRENGTHS OF SEWAGE

It is important to understand the various factors bearing inherently upon the quantity and quality of sewage, as discussed at length in this chapter.

Relation to Water Supply

Since sewage, broadly speaking, is the spent water supply of a community, it is important to note how this varies in different cities. One of the main differences in the composition of sewage in America as compared with that of European cities is the volume of water supply which dilutes the wastes reaching the sewers. While the water consumption of a city may not all reach the public sewers, particularly when water is used for sprinkling lawns and irrigating gardens, it is best to consider the public water supply as the first element in dealing with composition of sewage. Associated with the public water supply is the supply which is obtained from individual sources by manufacturing plants and other establishments using considerable water. For instance, at Memphis, Tenn., the City Water Department furnishes water to practically no large consumers. These secure their own water from the same underground strata as those serving the city supply. This fact accounts for a total use of water practically double the city supply which is about 70 gallons per capita daily.

In the course of investigations of the flow of sewage in different sections of the city of Toledo, Ohio, the authors found during the month of March, when there was no water used for lawn sprinkling, that based on pitometer surveys of the water consumption of three classes of residential districts and checked by gagings in the sewers built in practically impervious clay, there was a weighted average volume of water used in these residential districts and of sewage flow of 34 gallons per capita daily. In the highest type of residential district the water consumption was 48 gallons; in the poorest section of the community 15 gallons; and in the medium residential district 32 gallons.

The average water consumption at Toledo has ranged from 100 to 110 gallons per capita daily, of which 25 to 30 per cent is unaccounted for on the summation of individual meter readings. This percentage is explained by the use of water from unmetered sources in public buildings, sewer flushing, street washing, leakage of pipes, slip of meters, etc.

Not all of the metered water reaches the sewers as was found by study at Milwaukee in 1911, when the average daily consumption was 105 gallons per capita. This is illustrated in Table 1.

TABLE 1.—ESTIMATED QUANTITIES OF CITY WATER NOT REACHING THE SEWERS (MILWAUKEE, 1911)

Purposes	Gallons per capita per day	Per cent of total consumption
Steam railroads	5	4.76
Manufacturing and mechanical	5	4.76
Street sprinklers	5	4.76
Lawn sprinklers	2½	2.38
Consumers not connected to sewers	7½	7.14
Leakage from mains and services	15	14.28
Totals	40	38.08

In American cities there is a notorious waste of water in many instances as well as a more liberal use of water than found in most European cities. The Manual of Water Works Practice of the American Water Works Association gives, on page 428, records of average water consumption showing a wide range in gallons per capita daily, as follows:

Akron, Ohio	83
Atlanta, Ga	95
Baltimore, Md	132
Boston, Mass	113
Bridgeport, Conn	153
Buffalo, N. Y	213
Chicago, Ill	275
Cincinnati, Ohio	119
Cleveland, Ohio	142
Dallas, Texas	56
Denver, Colo	191
Detroit, Mich	134
Hartford, Conn	96
Kansas City, Mo	137
Los Angeles, Cal	125
Memphis, Tenn	70
Milwaukee, Wis	125
New Haven, Conn	130
New Orleans, La	100
New York, N. Y	131
Oakland, Cal	63
Philadelphia, Pa	168
Portland, Ore	124
Richmond, Va	108
Rochester, N. Y	84
San Antonio, Tex	114
San Francisco, Cal	81
Seattle, Wash	105
Springfield, Mass	91
St. Louis, Mo	140
St. Paul, Minn	78
Toledo, Ohio	110
Washington, D. C	132
Worcester, Mass	90

On the basis that all cities should have the same quantity of waste material entering the sewer for each inhabitant, it is seen

from the above table that there would be wide variations in sewage strength due to different dilutions.

The above comments apply to household wastes, but when it is realized that the actual flow in the sewers of many cities depends upon private as well as public water supplies, the washings from the streets at times of storms, where there are combined sewers, and that many industrial establishments have their own individual water supplies and turn into the sewers various industrial wastes, differing relatively in quantity and quality, it is obvious how important it is for those dealing with sewage disposal to study carefully all local factors related to the composition of sewage.

Private Water Supplies: Industrial Wastes

In the 1913 report on Plan of Sewerage for Cincinnati, it is shown that, while the city water supply averaged about 51 million gallons daily (131 gallons per capita), the industries consumed water, as follows:

Table 2.—Water Consumption and Wastes for Various Industries in Cincinnati—1913
(Million Gallons per Day)

Kind of plants	Water consumption			Total wastes
	City water works	Wells, canal, etc.	Total	
Soap factories	0.068	5.798	5.866	4.782
Paper mills	.....	4.500	4.500	4.500
Distilleries	0.054	2.235	2.289	2.289
Breweries	1.520	1.534	3.054	1.792
Slaughter and packing houses	0.547	0.854	1.401	1.401
Glue, fertilizers, greases, oils	0.116	0.635	0.751	0.671
Tanneries	0.077	0.592	0.669	0.669
Laundries	0.337	.....	0.337	0.337
Dairies	0.048	.....	0.048	0.048
Miscellaneous—tar, tar paper, ammonia, cotton and woolen manufacturing, galvanizing	0.046	0.709	0.755	0.755
Totals	2.813	16.857	19.670	17.244

The percentage[1] of public water supplies used for commercial and industrial purposes, in representative cities, is shown in Table 3.

TABLE 3.—PER CENT OF TOTAL CONSUMPTION USED FOR COMMERCIAL AND INDUSTRIAL PURPOSES

City	Total consumption, m.g.d.	Industrial and commercial consumption, m.g.d.	Per cent of total consumption as industrial and commercial
Akron, Ohio	16.6	2.5	15
Baltimore, Md	105.0	26.3	25
Bridgeport, Conn	23.0	12.0	52
Chicago, Ill	806.0	156.0	19
Kansas City, Mo	50.0	17.5	35
Milwaukee, Wis	69.0	45.0	65
New York, N. Y	800.0	175.0	22
Rochester, N. Y	26.0	6.7	26
Springfield, Mass	13.9	4.2	30

HOURLY VARIATIONS

At individual houses ordinarily there is a relatively small volume of water used late at night. At certain hours, say between seven and nine A. M., the hourly rate of consumption is greatly in excess of the average. The flow of outfall sewers reflects such characteristics more or less. As sewer systems increase in mileage the period of transit comes into play and hourly variations in flow of sewage at the outfall are far less in a city of several hundred thousand population than in a town of five or ten thousand.

Johnson, in his 1905 report at Columbus, Ohio, gave interesting comparisons of hourly variations in flows of the main outfall sewer which was an extension of an interceptor receiving the dry-weather flow and portions of the first flushings of the combined sewers with which that city is provided. It is noticeable that during dry weather there was quite a variation in the flow of

[1] From Manual of Water Works Practice.

sewage from this city having at that time a population of less than 200,000 people. (Table 4.)

TABLE 4.—HOURLY RELATION OF SUNDAY TO WEEK-DAY FLOWS AT COLUMBUS, OHIO

Hour ending	Per cent which hourly rate of discharge is of the average		
	Sunday	Week day	Average
1 A. M.	105	83	86
2 A. M.	103	80	82
3 A. M.	97	77	79
4 A. M.	95	75	78
5 A. M.	91	74	76
6 A. M.	90	73	75
7 A. M.	90	73	75
8 A. M.	90	78	79
9 A. M.	96	97	96
10 A. M.	101	111	110
11 A. M.	105	118	117
12 M.	108	123	121
1 P. M.	108	124	122
2 P. M.	108	125	122
3 P. M.	108	125	122
4 P. M.	108	125	122
5 P. M.	107	125	122
6 P. M.	105	124	121
7 P. M.	103	117	114
8 P. M.	101	115	104
9 P. M.	100	97	98
10 P. M.	100	94	94
11 P. M.	99	90	91
12 P. M.	96	88	89

Corresponding data from different sewerage districts at Cincinnati, taken from the 1913 report, are shown in Table 5.

TABLE 5.—RATE OF SEWAGE FLOW AT CINCINNATI FOR EACH HOUR OF THE DAY, IN PER CENT OF THE AVERAGE RATE

Time	Residential districts		Commercial districts								Industrial district
	Ross Run	Mitchell Avenue	Sycamore Street	Main Street	Walnut Street	Vine Street	Race Street	Elm Street	Plum Street	Central Avenue	Marshall Ave.
1 A. M.	63	75	33	71	55	60	42	38	77	72	59
2 A. M.	58	73	31	71	52	57	41	36	77	72	60
3 A. M.	53	71	33	71	50	57	41	34	77	71	61
4 A. M.	51	70	35	71	50	58	41	34	80	71	63
5 A. M.	52	72	40	71	55	60	41	38	84	72	66
6 A. M.	64	80	53	75	66	66	48	49	89	76	81
7 A. M.	112	105	74	96	92	85	67	97	100	93	105
8 A. M.	162	153	126	139	144	128	145	151	118	113	129
9 A. M.	171	162	171	147	156	141	174	170	130	126	134
10 A. M.	167	156	190	147	158	148	175	177	134	136	138
11 A. M.	157	138	191	140	154	150	174	180	137	139	140
12 M.	148	123	190	135	150	152	173	178	137	139	141
1 P. M.	139	114	185	128	144	152	171	174	132	137	141
2 P. M.	128	108	180	120	136	151	169	165	125	136	141
3 P. M.	118	105	172	116	128	147	168	153	118	131	136
4 P. M.	109	101	159	109	123	136	165	140	107	128	126
5 P. M.	102	98	136	102	113	118	155	124	100	122	116
6 P. M.	94	95	107	98	105	99	89	106	96	108	105
7 P. M.	88	92	72	91	97	89	71	90	86	89	94
8 P. M.	82	89	56	88	91	81	62	75	84	80	86
9 P. M.	79	86	48	85	82	74	53	62	80	72	80
10 P. M.	74	84	42	81	75	68	47	52	77	72	73
11 P. M.	70	80	39	75	66	63	42	45	77	72	68
12 P. M.	66	77	36	72	61	60	42	40	77	72	63

These figures have been computed from the average or conventional curves for the several sewer districts.

Sunday flow has not been included in preparing these conventional curves.

GROUND WATER INFILTRATION AND ROOF WATER

It is frequently found, where sewers are built on the separate system, that the flows of sewers on many occasions are greatly in excess of what can be justified from records of water consumption. Two main factors to be taken into account are the infiltration of ground water due to leaky joints in street sewers and house connections, and to the discharge of roof water, which frequently is a substantial item even in cities where by ordinance such discharge of roof water into sanitary sewers is forbidden.

The authors have noted cases where leaky sewers on the separate system have produced average annual flows of sewage three times in excess of the water consumption. Ground water in fully

sewered areas is usually assumed to range from 500 to 2000 gallons per acre daily.

Grams of Household Wastes per Capita Daily

Probably the best data on the amount of constituents of domestic sewage are to be found in early English data. Letheby's table (Table 6) relates to a study of representative flows at 10 outfall sewers of the city of London built on the combined plan. Evidently the constituents designated for other refuse represents the difference between the London total figures and those obtained from various hospital data as to the excreta of representative persons.

Table 6.—Letheby's[1] Estimate of the Average Amount of the Principal Constituents of City Sewage, in Grams per Capita Daily

		Total	From excreta	From other refuse
Organic nitrogen	Total	15.1	10.1	5.0
	Dissolved	13.2	0.1	4.1
	Suspended	1.9	1.0	0.9
Dissolved matters	Total	136.0	43.0	93.0
	Mineral	98.5	10.0	88.5
	Organic and volatile	37.5	33.0	4.5
Suspended matters	Total	93.0	19.0	74.0
	Mineral	53.5	3.0	50.5
	Organic and volatile	39.5	16.0	23.5
Total solids	Total	229.0	62.0	167.0
	Mineral	152.0	13.0	129.0
	Organic and volatile	77.0	49.0	28.0
Phosphoric acid	Total	4.3	2.4	1.9
	Dissolved	2.1	1.4	0.7
	Suspended	2.2	1.0	1.2
Potash	Total	3.3	1.9	1.4
	Dissolved	2.9	1.5	1.4
	Suspended	0.4	0.4	

[1] The Sewage Question, p. 137, published in London in 1872 by Balliere, Tyndall and Cox.

The Baumeister data (Table 7) deal with other English cities as well as London and are founded upon the data of the Royal Commission on River Pollution in the early seventies.

Table 7.—Baumeister's[1] Estimate of the Average Amounts of the Principal Constituents of Sewage, in Grams per Capita Daily

		London	Average of sixteen English cities
Total nitrogen		16	15
Dissolved matter		129	127
Suspended matter	Total	122	79
	Mineral	71	43
	Organic and volatile	51	36
Total solids		251	206

[1] Goodell's translation of "The Cleaning and Sewerage of Cities," 1891 (German edition 1890) by Prof. R. Baumeister.

Looking at these data in the light of more recent records, it would seem that the English data might in some instances have been influenced by cesspools which retain certain portions of the solid matters. Fuller studied this matter at considerable length for Massachusetts cities in the early nineties and in his book[1] indicates that later data for Massachusetts plants and those at Plainfield, N. J. and Reading, Pa. led to an increase of about 25 per cent in the estimated total suspended matter. He gives for separate and combined sewers data shown in Table 8.

Table 8.—Estimated Average Quantities of Principal Constituents in Grams per Capita Daily of Sewages of Various Types

		Separate sewers	Combined sewers			
			London	Columbus	Chicago	Providence
Oxygen consumed, boiled 5 minutes		20	25	30	42[1]	35
Total nitrogen		16	13	14.4	18.5	17
Chlorine		18	24	32	44	...[2]
Suspended matters,	Total	60	87	98	155	150
	Mineral	10	41	51	89	20[2]
	Organic and volatile	50	46	47	66	130[2]
Fats		..	..	19.1	26	

[1] 30 minutes boiling.
[2] Results distorted by the presence of sea water.

The latest available data on per capita constituents of sewage are from Bulletin No. 132, U. S. Public Health Service. Table 9 summarizes them.

[1] Fuller's Sewage Disposal, p. 9.

Table 9.—Average Constituents of Raw Sewage in Grams per Capita Daily
(U. S. Public Health Service, Public Health Bulletin No. 132)

	Separate sewers				Combined sewers*			
	Alliance, O.	Baltimore, Md.	Canton, O.	Reading, Pa.	Columbus, O.	Fitchburg, Mass.	Lexington, Ky.	Rochester (Irondequoit)
Oxygen demand								
1 day	18	24	29	24	29	25	22	23
5 days	46	48	52	45	68	52	48	54
Oxygen consumed								
30 min. at 100° C.	19	17	15	17	23	22	11	20
Suspended matter	75	64	63	55	74	99	56	98
Ether soluble matter	18	16	15	10	36	21	19	18
Chlorides (as Cl)	23	34	19	46	40	23	30	43
Av. dry weather flow, m.g.d.	2.62	55.0	4.44	6.04	21.2	3.35	2.5	33.0
Contributing population	20,000	520,000	70,000	60,000	225,000	38,000	28,000	240,000
Gallons sewage per capita	131	106	64	101	94	88	89	137

Note.—Comprises data collected May to Dec. 1920, an average of 16 days being spent at each plant to secure about 12 analyses. Methods of sampling and analysis uniform throughout. (Basic figures, pages 115–116.)

* Apparently dry weather flow-observations and hence probably not characteristic of combined sewage of average quality.

There has been some variation in the methods of analyses during recent years in the laboratories of this and other countries. Particularly has there been a tendency recently to make fewer determinations of samples collected. No discussion is given here of methods of analyses, but reference is made to Standard Methods for the Examination of Water and Sewage, already cited.

While representative average analyses are of much significance, it is important to realize that wide fluctuations in the composition of samples collected at different hours of the day and even at different months of the year are to be expected. Actual records, for different days at Columbus, by Johnson illustrate this in Tables 10, 11 and 12.

The widely varying analyses presented in the preceding tables show how capricious the results of instant or discontinuous sampling would be in the building up of assumptions as to the future load of impurities which sewage treatment plants can be expected to carry.

Differences in analyses (Tables 13 and 14) of the Baltimore and Indianapolis sewages, when stated as monthly averages, are

TABLE 10.—COMPARISON OF THE PERCENTAGES WHICH THE FLOW OF SEWAGE AND THE AMOUNT OF ITS DIFFERENT CONSTITUENTS AT DIFFERENT HOURS ARE OF THE AVERAGE FOR THE DAY

Hour	Rate of flow	Residue on evaporation			Nitrogen as		Oxygen consumed	Chlorine
		Total	Dissolved	Suspended	Free ammonia	Alb. ammonia		
9–10 A. M.	124	143	126	180	150	180	158	99
11–12 A. M.	116	160	159	162	157	155	167	114
1– 2 P. M.	123	129	131	125	107	107	110	127
3– 4 P. M.	116	142	114	204	113	141	141	120
5– 6 P. M.	107	123	137	93	116	99	92	217
7– 8 P. M.	103	97	105	79	141	117	110	116
9–10 P. M.	92	67	76	49	84	66	85	75
11–12 P. M.	85	84	76	101	98	87	99	77
1– 2 A. M.	74	35	43	16	35	31	22	53
3– 4 A. M.	70	28	39	6	8	15	16	38
5– 6 A. M.	77	32	44	8	16	14	19	38
7– 8 A. M.	69	74	59	59	101	87	82	61

TABLE 11.—COMPARISON OF THE PERCENTAGES WHICH THE FLOW OF SEWAGE AT THE COLUMBUS OUTFALL AND THE AMOUNT OF ITS DIFFERENT CONSTITUENTS AT DIFFERENT HOURS ARE OF THE AVERAGES FOR THE DAY

Hour		12 A. M. to 2 A. M.	2 A. M. to 4 A. M.	4 A. M. to 6 A. M.	6 A. M. to 8 A. M.	8 A. M. to 10 A. M.	10 A. M. to 12 M.	12 M. to 2 P. M.	2 P. M. to 4 P. M.	4 P. M. to 6 P. M.	6 P. M. to 8 P. M.	8 P. M. to 10 P. M.	10 P. M. to 12 P. M.
Rate of flow		88	83	80	89	113	117	115	117	115	103	92	89
Oxygen consumed	Total	35	69	28	28	176	116	123	117	197	88	90	58
	Dissolved	42	23	29	29	181	136	149	149	149	81	87	68
	Suspended	27	123	27	27	169	92	92	81	254	96	92	46
Nitrogen as	Ammonia	73	56	42	49	108	109	110	167	147	99	99	84
	Organic	47	31	23	28	167	117	115	126	225	84	80	63
Chlorine		72	74	73	69	94	143	123	111	111	101	114	80
Suspended matter	Total	59	43	37	37	213	145	110	110	165	94	54	52
	Volatile	29	28	18	29	156	160	129	109	229	109	64	50
	Fixed	81	53	52	43	257	134	96	112	116	83	46	54
Fats		33	26	30	22	81	111	111	81	307	163	81	74
Bacteria per cubic centimeter		75	47	36	56	92	167	139	167	103	125	106	81

TABLE 12.—SHOWING THE DAILY VOLUME OF EXTREME DRY-WEATHER SEWAGE FLOW AT COLUMBUS, OHIO
(Million Gallons)

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
7.3	9.1	8.5	8.5	8.4	8.6	8.6

noticeable and accentuate the need of comparing such analyses with sound basic data to offset local influences at times of sampling due to fluctuating dilutions, depositing and stranding of solids, etc.

TABLE 13.—BALTIMORE SEWAGE TREATMENT WORKS
(Raw Sewage Analyses, Separate System, Monthly Averages)

1925, month	Suspended solids p.p.m.	Settling solids p.p.m.	Biochemical oxygen demand p.p.m.	Bacteria per cubic centimeter	
				On plain agar at 37° C.	Acid formers on litmus-lactose agar at 37° C.
Jan.	318	218	176	2,000,000	590,000
Feb.	171	106	139	4,900,000	600,000
Mar.	320	294	200	1,800,000	330,000
Apr.	549	440	144	2,100,000	1,500,000
May	671	614	218	2,200,000	830,000
June	392	284	177	6,900,000	1,200,000
July	392	306	154	3,100,000	830,000
Aug.	810	610	175	3,200,000	1,100,000
Sept	723	696	222	12,600,000	5,900,000
Oct.	649	623	228	5,100,000	1,900,000
Nov	751	635	165	3,600,000	1,000,000
Dec	459	378	151	1,800,000	430,000

TABLE 14.—INDIANAPOLIS SEWAGE WORKS
(Raw Sewage Analyses, Combined System, Monthly Averages, Parts per Million)

Month	Year	Nitrogen as			Oxygen consumed			Chlorine	Suspended matter
		Organic	Free ammonia	Nitrite nitrate	Total	Dissolved *	Suspended *		
Apr.	1914	8.4	5.5	2.4	44.0	....	....	85	157
May	1914	18.0	6.0	1.5	51.0	22.7	22.5	100	169
June	1914	19.3	7.6	0.8	36.0	13.5	22.5	119	184
July	1914	22.1	7.4	0.2	39.7	15.7	22.6	133	227
Aug.	1914	17.7	6.1	0.0	46.7	17.6	30.0	123	232
Sept.	1914	16.3	5.5	0.0	50.0	16.8	33.2	100	251
Oct.	1914	14.6	5.2	0.0	42.7	16.2	26.5	101	244
Nov.	1914	20.2	7.9	0.0	46.0	24.0	25.0	120	251
Dec.	1914	19.3	7.5	0.1	69.0	25.0	44.0	122	230
Jan.	1915	23.1	6.1	0.1	54.0	23.0	31.0	125	158
Feb.	1915	15.6	5.4	0.0	40.0	29.0	11.0	120	218
Mar.	1915	....	...	....	....	....	....	...	180
Mean	....	18.62	6.38	0.46	47.2	20.4	26.8	116.3	200

* For part of samples only.

The results of studies by the U. S. Public Health Service on the composition of raw sewage at well known treatment plants are shown in Table 15. Further suggestive data appear in Table 16.

TABLE 15.—ANALYSES OF RAW SEWAGES[1]
(From Public Health Bulletin No. 132, U. S. Public Health Service)

Place 1920	Parts per million						
	Suspended solids	Oxygen consumed 30′ in boiling H_2O	Alkalinity as $CaCO_3$ by M.O.	Chlorine as chlorides	Biochem. O-demand 20° C± 5 day	Dissolved oxygen	Ether soluble matter
Alliance, Ohio.......	152	38	184	47	92	3.0	37
Atlanta, Ga. (Intrenchment Creek)	106	35	78	93	63	0.0	104
Atlanta, Ga. (Peachtree Plant).......	226	35	68	86	52	0.0	83
Baltimore, Md......	159	43	136	86	120	0.2	40
Canton, Ohio.......	261	61	342	79	213	0.5	62
Columbus, Ohio......	207	63	211	113	190	1.7	100
Fitchburg, Mass.....	297	65	97	70	155	0.3	63
Houston, Texas (North Side)......	200	45	270	136	116	0.2	39
Houston, Texas (South Side)......	226	38	304	101	112	0.8	36
Lexington, Ky.......	166	32	196	89	144	0.1	58
Reading, Pa........	145	45	164	120	118		25
Rochester, N. Y. (Brighton Plant)..	101	24	178	45	67	3.7	16
Rochester, N. Y. (Irondequoit Plant)	188	39	175	82	104	0.9	34
San Marcos, Texas..	110	29	306	83	67	2.8	18
Sherman, Texas.....	264	64	415	129	202	2.5	69

[1] Investigations from May 27 to Dec. 1, 1920, an average of 16 days being spent at each plant, by a chemist of the U. S. Public Health Service, to secure a series of about 12 analyses.

TABLE 16.—RAW SEWAGE CHARACTERISTICS
(U. S. Public Health Service, Public Health Bulletin No. 132, p. 118. Original Information from 1914 Report Cleveland Sewage Testing Station)

Place	Parts per million			
	Suspended solids	Oxygen consumed 30′ in boiling water	Chlorine as chlorides	Ammonia nitrogen
Chicago, Ill.............	141	38	40	8.8
Waterbury, Conn.........	105	46	48	7.8
Cleveland, Ohio...........	252	50	246	12.0
Philadelphia, Pa..........	189	76	39	4.0
Akron, Ohio..............	238	86	917	6.6
Columbus, Ohio...........	215	93	65	11.0
Gloversville, N. Y.........	406	95	158	12.0

STREET WASH: STORM FLOWS

When storms come, the flow of combined sewers shows unusually high quantities of impurities, coming from the street wash and from the scouring of deposits lodged in the sewers during dry weather. After a time these solids are washed into and out of the sewers and the sewage, on account of dilution by storm water, shows less impurities than during dry weather.

The Royal Commission on Sewage Disposal in its Fifth Report, Appendix 5, gives observations on the composition of sewage at Macclesfield due to storm flows following 0.10 inch rainfall at the end of 8 days of dry weather. The results are summarized in Table 17.

TABLE 17.—MACCLESFIELD STORM SEWAGE
(July 1, 1902)

Time, P. M.	2:45	3:00	3:15	4:00
Flow × D. W. F.	3	4	6	3
Parts per million				
Ammoniacal nitrogen	40.8	51.9	34.1	15.5
Albuminoid nitrogen	11.1	32.1	40.7	9.1
Total organic nitrogen	22.6	92.0	82.3	19.3
Oxygen absorbed, 4 hrs., 26.7° C.	157.0	369.0	372.4	97.5
Chlorine	109.0	118.8	75.6	42.6
Suspended solids, total	581	2463	2588	327
Suspended solids, volatile	459	1054	1179	148
Dissolved solids	638	899	515	464

The effect of changing character of vehicular traffic, from horse to motor drive, upon the possible quantity of street wash is shown, for example, in Table 18.

TABLE 18.—COMPARATIVE DATA ON STREET CLEANING AT TORONTO[1]

Year	No. of men employed	Refuse removed cubic yards	Miles of paved street
1914	440	139,000	323.02
1925	138	75,000	446.41

[1] McLean, "Influence of Modern Highway," Journal of Engineering Institute of Canada Vol. IX, No. 2, February, 1926, p. 98.

TABLE 19.—CHEMICAL AND BACTERIAL ANALYSES OF RAW SEWAGE AT COLUMBUS

Nature of sample	Parts per million																				Free carbonic acid	Fats	Bacteria per cubic centimeter
	Oxygen consumed			Nitrogen as						Chlorine	Residue on evaporation												
				Organic			Free ammonia	Nitrites	Nitrates		Total			Volatile			Fixed						
	Total	Dis-solved	Sus-pended	Total	Dis-solved	Sus-pended					Total	Dis-solved	Sus-pended	Total	Dis-solved	Sus-pended	Total	Dis-solved	Sus-pended				
(a)	59	28	31	12.3	4.6	7.7	16.7	0.00	0.1	66	1056	852	204	207	109	98	849	743	106	38	38	4,000,000
(b)	56	28	28	9.7	3.6	6.1	11.5	0.09	0.2	67	1026	811	215	190	109	81	836	702	134	28	27	3,700,000
(c)	79	24	55	11.5	2.6	8.9	10.5	0.05	0.3	60	1333	715	618	262	119	143	1071	596	475	27	38	5,000,000

(a) Extreme dry weather sewage—average of 54 analyses.

(b) Average sewage—computed from 282 analyses consisting of 13,536 half-hourly portions corrected for effect of method of mixing equal portions throughout the 24 hours as follows: On July 7, 1905, an hourly series was taken at outfall sewer; from average of these results and an average weighted according to sewage flow the percentage changes in constituents were computed and applied as factors to the average results.

(c) Storm average—average of 10 analyses.

Johnson gives valuable data in his 1905 Report at Columbus, page 28, on comparisons of dry weather flow (D. W. F.) average and storm or wet weather flow (W. W. F.). These are set forth in Table 19.

Loadings for treatment plants can be more adequately studied by comparing foregoing data as to grams per capita for average flows of separate and combined sewers.

INDUSTRIAL WASTES

This is a special subject for investigation for each city when industries discharge substantial quantities of wastes into the sewers. At Chicago the industrial wastes are equal to the domestic wastes of a population of over 1,500,000 persons. Sometimes the wastes are acid and germicidal, sometimes not. Each plant should be studied by itself.

Eddy has pointed out the great increase in weight of sewage constituents due to industrial wastes in the following rough estimates:

City	Increase in per cent	
	Suspended solids	Oxygen consumed
Akron—rubber reclaiming plant wastes...	120	140
Chicago—packing house district only—packing house wastes................	460	225
Dayton—paper mill wastes.............	60	25
Fort Worth—packing house wastes.......	65	...
Gloversville—tannery wastes............	155	115
Milwaukee—portion only of city, packing house and tannery wastes.............	70	10

The discharge of wastes into the sewers was equivalent to increasing the population in these cities from 60 to 460 per cent or from 10 to 225 per cent, as measured by the suspended solids and oxygen consumed, respectively.

BIOCHEMICAL OXYGEN DEMAND

For many decades the amount of organic matter in sewage has been determined by albuminoid ammonia and oxygen consumed from potassium permanganate.

TABLE 20.—PER CAPITA OXYGEN DEMAND OF SEWAGE
(Pounds per Day)

Place	Total‡ oxygen demand (Pounds per capita per day)	Reference
Alliance, Ohio*	0.15	Computed from data in United States Public Health Bulletin No. 132, pp. 35–111. Data cover period of one to two weeks at each place. Average of eight cities, 0.17.
Baltimore, Md.*	0.15	
Canton, Ohio*	0.17	
Columbus, Ohio†	0.22	
Fitchburg, Mass.†	0.17	
Houston, Tex. (North Plant)†	0.16	
Reading, Pa	0.15	
Rochester, N. Y. (Irondequoit Plant)†	0.18	
Dayton, Ohio*	0.20	Metcalf and Eddy; 24-hour composite sample.
Schenectady, N. Y.*	0.20	Average of ten catch samples in 1924.
Syracuse, N. Y.†	0.21	Metcalf and Eddy; computed on sample of canal water carrying sewage.
Cincinnati, Ohio†	0.22	Average of long series of tests by United States Public Health Service on sewage from one of the city's sewers by 5-day dilution method.
Peoria, Ill	0.25	Average result computed from net oxygen demand of river water above and below Peoria for period of investigation by United States Public Health Service, 1921–22.
Chicago Sanitary District,† 39th Street sewage, tests in 1914 by nitrate method	0.24	Computed from average of 179 determinations during 1914 of 10-day oxygen demand by nitrate method.
Tests in 1920 at Chicago by—		
Nitrate method	0.261	Computed from results of 10-day test on six samples per day for 27 days during November and December, 1920
Dilution method	0.266	

* Separate sewers. † Combined sewers. (Dry weather flow.) ‡ Twenty day demand.

Table 22 shows the estimated total dry sludge or suspended matters in various sewages.

Since gas collection has become an item of interest, records are of value showing the solid matters which are volatile, that is, capable of being ignited and presumably of an organic nature. The data in Table 23, from Metcalf and Eddy, are valuable for reference. Grams per capita data are converted into pounds per capita by multiplying by the factor 0.00221, and into tons per 1000 population per annum by 0.403.

TABLE 23.—SUSPENDED SOLIDS IN SEWAGE[1]
(Grams per Capita Daily)

	Suspended solids		Fats
	Total	Volatile	
Brockton	118	103	
Clinton	57	44	
Gloversville	236	133	28
Worcester	112	71	
Average manufacturing cities	131	88	
Boston	102	69	
Chicago	155	89	25
Columbus	96	36	11
Providence	157	136	
Milwaukee (Est.)	100	60	40
Average large cities with combined sewers	122	78	25
Andover	101	70	
Concord	296	237	
Leicester	38	28	
Spencer	57	43	
Stockbridge	35	30	
Average rural residential community	105	82	
Framingham	117	97	
Hudson	84	63	
Marlboro	61	51	
Natick	45	36	
Pittsfield	29	24	
Westboro	40	35	
Average of small Massachusetts towns	58	49	
6 English cities—average	126		
13 German cities—average	153	82	

[1] Compiled from Metcalf and Eddy, Sewage Disposal.

DISSOLVED OXYGEN

When the spent water supply receives household wastes at the point of origin and enters the sewer system, it contains the dissolved oxygen of the water supply. Putrefaction promptly gets underway and, as explained in later chapters, this means a progressive diminution and final elimination of dissolved oxygen.

At the outfall of small sewer systems the time interval for the flow of sewage from the point of origin to the outlet is usually such that dissolved oxygen is always present in the sewage. In very large sewer systems the period of transit for the sewage is such that dissolved oxygen may be always absent. Between these extremes are various intermediate conditions. For moderately sized sewer systems dissolved oxygen is quite frequently absent during daylight hours when the sewage flow is greatest, but is present during a portion of the 24-hour period when the sewage is relatively weak.

FATS AND GREASE

Special emphasis must be placed upon the nature and quantity of fats and greases which may reach treatment works. The actual conditions to be found depend upon practically all of the controlling elements already discussed in this chapter and upon what efforts are made in each locality to keep such material out of the sewers. Operating experience has shown quite clearly that undue amounts of these constituents are of considerable importance in interfering with normal treatment processes. The operation of an activated sludge plant, for example, is considerably disturbed by intermittent discharges of oil from the sewers. Where dilution only is used for disposal, unsightly situations may frequently arise, unles due precautions to avoid them are taken.

Table 22 shows the estimated total dry sludge or suspended matters in various sewages.

Since gas collection has become an item of interest, records are of value showing the solid matters which are volatile, that is, capable of being ignited and presumably of an organic nature. The data in Table 23, from Metcalf and Eddy, are valuable for reference. Grams per capita data are converted into pounds per capita by multiplying by the factor 0.00221, and into tons per 1000 population per annum by 0.403.

TABLE 23.—SUSPENDED SOLIDS IN SEWAGE[1]
(Grams per Capita Daily)

	Suspended solids		Fats
	Total	Volatile	
Brockton	118	103	
Clinton	57	44	
Gloversville	236	133	28
Worcester	112	71	
Average manufacturing cities	131	88	
Boston	102	69	
Chicago	155	89	25
Columbus	96	36	11
Providence	157	136	
Milwaukee (Est.)	100	60	40
Average large cities with combined sewers	122	78	25
Andover	101	70	
Concord	296	237	
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CHAPTER V

BASIC DESIGN DATA: RATIONAL METHODS

SYNOPSIS

1. Forecasts of Quantity.—These should be made with greatest care, taking into account the portion of public water supply entering the sewers, the seepage entering per mile of sewers through leaky joints, and the volume of sewage to be expected from commercial and industrial developments, including private water supplies. All data pertinent to the design of sewers should be studied for quantity of flow corresponding to a given future date, since pumps, conduits, tanks and other devices require their capacity to be rated against volumes to be actually dealt with.

2. Forecasts of Constituents.—For household wastes this can be done on a per capita basis and adjusted to future population. The weight of street wash constituents should be estimated. The same should be done for industrial wastes, studied both at the point of origin and after mixing takes place en route to the outfall. Frequently it is helpful to express the organic content of industrial wastes in terms of the human population which would place an equivalent load on oxidizing facilities.

3. Rational Method of Estimating.—Sewage disposal projects ordinarily require estimates to be made of their future loadings, both as to volume and composition of flow. By so doing, works are more adequately designed, and there is a lessening of cases where works fail to give reasonable performance, such as found at plants which are "drowned out" by seepage as soon as built. The wisest course to pursue is to consider rationally each element as outlined in Chapter IV and thus build up sound basic data for design.

SCOPE OF DESIGN PROBLEMS

Many sewage disposal problems have related to extensions to plants receiving sewage which for years had not changed materially as shown by analyses year after year. On the other hand, the war showed that industries frequently have fluctuating

effects on city sewage and that it is dangerous to follow too closely past precedents and conditions in providing for the future. In particular is it unwise to adopt for one town basic design data from another locality, without studying the conditions as to comparability.

In considering design data for a comprehensive plan for developing both old and new projects for a term of years, it is highly important to give due consideration to the various items set forth in Chapter IV. Failure to do so sometimes gives unsatisfactory results.

Rational Method for Sewer Design

In the design of sewers the rational method of taking into account various local factors in line with reasonable assumptions has largely taken the place of empirical formulas. For sewer designs the rational method is well set forth in numerous text books and technical papers.

Many of the data considered in designing sewer capacity also have a direct bearing on the concentration of the sewage, through the dilution which the volume of sewage provides for various wastes reaching the sewers.

The volume of sewage from an estimated future population, as rationally deduced for sewer design, is directly applicable to matters of tank capacity and size of pumps, pipes and other arrangements.

Tables 25 to 28 at the end of this chapter are taken from Jones'[1] description of the Toledo intercepting sewer design by the authors. The data therein indicate some of the information that should rationally be considered in estimating the strength as well as the volume of future sewage flow. They are included here as suggestive and illustrative material which clarify the procedures noted above. Their careful review will no doubt clarify the concepts adequately.

RATIONAL METHOD FOR ESTIMATING FUTURE SEWAGE COMPOSITION

For years the future loadings of treatment plants and dilution projects have been considered in terms of population per unit of treatment arrangement or with reference to a given proportionate volume of strong, medium or weak sewage.

[1] Engineering News-Record, Vol. 96, April 1, 1926, pp. 526–529.

As knowledge has advanced it is now desirable to rate such loadings in more precise terms. The quality of suspended matter, for example, is of importance in estimating the size of sludge digestion arrangements and sludge drying facilities. The amount of volatile (organic) sludge affects the amount of gas production. Again, the total organic matter is related to oxygen demand both in oxidation processes and in dilution in streams.

From what has been given in Chapter IV as to constituents of domestic sewage in grams per capita daily, it is feasible to estimate the future strength of sewage for a given population, if we assume rationally what the volume or dilution per capita will be.

Similarly, if we deal with combined instead of separate sewers, we can approximate the added impurities coming from street wash. If the future flow is to be partly from combined and partly from separate sewers, the main items of sewage composition can be correspondingly estimated.

Industrial wastes sometimes approach in importance the impurities coming from domestic wastes and street wash. They should certainly be taken into account, and this involves a rational study of them at their source in the light of a reasonable future program.

As an example of this rational method of estimating some of the principal constituents of future sewage flows Fuller in 1917 in a preliminary report on sewage disposal at Indianapolis prepared an estimate as shown in Table 24. This is merely an illustration of how some of the basic data may be more reliably developed by study of local conditions than by assuming that future sewage flows will have analyses about as they were in the past. This rational method can now be applied with more reliability than when attempted at Indianapolis and can be considered for other important items. Enough has been said, however, to indicate the significance of this branch of basic design data for sewage disposal projects.

Attention is particularly directed in Table 24 to the fact that estimated unit quantities of suspended matter in sanitary sewage are multiplied by the population connected with the sewers, while street wash is pro-rated to the total population.

At the North Side, Chicago, plant of the activated sludge type, the volume of sewage from various sources was estimated in gallons per capita daily at 219 in 1930 and 155 in 1960. The reduction is explained largely by proposed metering of the city water supply.

TABLE 24.—SEWAGE DISPOSAL DESIGN DATA, INDIANAPOLIS, IND.

		1915	1925	1930
Total population		272,000	343,000	379,000
Population connected with sewers		140,000	220,000	265,000
Av. dry weather sewage flow, million gallons daily		48.8[1]	44	53
Av. dry weather sewage, gallons per capita daily (total population)		178.0	128.0	140.0
Av. dry weather sewage, gallons per capita daily (connected population)		348.0	200.0	200.0
Av total suspended matter, parts per million		200.0	240.0	220.0
Av. total suspended matter, tons per million gallons		0.83	1.00	0.92
Av. total suspended matter, tons per year		13,100	16,700	18,300
Tons annually of total suspended matters	Sanitary sewage[2]	3,500	5,500	6,625
	Street wash[3]	4,100	5,200	5,675
	Trade waste[4]	5,500	6,000	6,000
	Total	13,100	16,700	18,300
Annual pumpage, of dry weather flow in million gallons, plus about 5 per cent for wet weather pumpage between av. dry weather flow and 100 million gallons daily		....	17,000	20,000

[1] To be reduced by eliminating clean water from industrial plants.
[2] Taken at 25 tons per 1000 population annually (Plainfield and Mass. data).
[3] Taken as 15 tons per total, population in thousands; obtained by subtracting 25 tons per 1000 population from cities with separate sewers from 40 tons per 1000 population, which is a Columbus, Ohio, record.
[4] 1915 figure obtained by difference, which is increased about 10 per cent, and held constant.

TABLE 25.—PRESENT AND ESTIMATED 1960 AREA AND POPULATION, TOLEDO, OHIO

Drainage area	Present population	Present area, acres	1960 population	1960 area, acres
Ten Mile Creek	60,000	4,000	310,000	20,000
Swan Creek	75,000	4,000	194,000	13,000
West Side River	75,000	4,000	111,000	4,000
East Side River	40,000	4,000	165,000	10,500
Totals	250,000	16,000	780,000	47,500

TABLE 26.—RELATIONS OF INDUSTRIAL, COMMERCIAL AND DOMESTIC FLOWS FOR VARIOUS CITIES (Design Basis)

	Toledo	Milwaukee	Detroit	Buffalo	Cincinnati	Louisville	Fitchburg
Date of ultimate estimate	1960	1950	1940	1950	1950	....	1940
Population	781,900	862,000	1,500,000	800,000	720,000	230,000	87,200
Industrial area, acres	4,139.05	3,762	4,800	4,065	8,180	622	1,256
Commercial area, acres	837.60	84	700	568	723	66	
Industrial, g.a.d.*							
Av., used in design	8,000	9,350	8,000	....	4,500	....	4,444
Max., used in design	12,000	16,800	12,000	16,000	9,000	24,000	8,000
Commercial g.a.d.*							
Av., used in design	15,000	17,700	33,000				
Max., used in design	30,000	29,800	50,000	60,000	40,000	30,000	
Industrial g. per 1000 pop.							
Av	42,340	40,900	25,600	....	51,000	....	66,800
Max	63,510	73,400	38,400	81,500	102,000	....	115,650
Commercial g. per 1000 pop.							
Av	16,060	17,400	15,400				
Max	32,120	29,200	23,400	42,600	40,100	8,160	
Ground water, g.a.d.*							
Av	600	1,660	....	....	750		
Max	800	1,660	500–1,000	1,000–1,850	750	1,960	
Domestic gal. per cap.							
Av. for year	52	50					
Av. max. days	65	50	114	....	86	100	75
Max. rate	113†–158†	125	228	285	135	200	150

* g.a.d. = gallons per acre daily.

† Maximum rate depends on population of drainage area.

Table 27.—Present and Future Relations of Industrial and Commercial Areas to Population for Various Cities

	Toledo	Milwaukee	Detroit	Buffalo	Cincinnati	Louisville, Bear Grass Creek	Fitchburg
Date of design	1919	1910	1915	1915	1913	1906	1911
Date of ultimate estimate	1960	1950	1940	1950	1950	....	1940
Population							
Date of design	254,700	414,000	768,746	....	402,000		37,320
Date of ultimate estimate	781,900	862,000	1,500,000	800,000	720,000	230,000	87,200
Ultimate population per acre	16.6	22.8	20.1	32.0	8.0	29.5	10.7
Area, acres*							
Date of design	15,945.00	16,400	30,200	....	44,800		
Date of ultimate estimate	47,299.80	37,790	74,500	24,928	89,600	7,829	8,134
Industrial area, acres							
Date of design	807.10	1,670					
Date of ultimate estimate	4,139.05†	3,762	4,800	4,065	8,180	622	1,256
Commercial area, acres							
Date of design	137.30	281					
Date of ultimate estimate	837.60	847	700	568	723	66	
Industrial area per 1000 population, acres							
Date of design	3.17	4.04					
Date of ultimate estimate	5.30	4.36	3.20	5.08	11.40	2.70	14.4
Commercial area per 1000 population, acres							
Date of design	0.54	0.68					
Date of ultimate estimate	1.07	0.98	0.47	0.71	1.10	2.90	
Per cent industrial is of total							
Date of design	5.06	10.2					
Date of ultimate estimate	8.76	10.0	6.0	16.3	9.1	8.0	15.4
Per cent commercial is of total							
Date of design	0.86	1.70					
Date of ultimate estimate	1.77	2.24	0.94	2.28	0.80	0.85	

Note.—Data on which above table is based are found in the Milwaukee Report for 1915, Cincinnati Report for 1913, Buffalo Report for 1915, Detroit Report for 1915, Louisville for 1910, Ten Mile Creek West Side, and East Side River Investigations, Toledo, Ohio, 1916–18, Fitchburg Report for 1911.

* All areas are in acres.

† Including 341.00 acres, industrial area, not in drainage area.

TABLE 28.—RELATION OF DOMESTIC, INDUSTRIAL AND COMMERCIAL SEWAGE FLOWS AND GROUND WATER ALLOWANCES USED AS BASES OF DESIGN OF INTERCEPTING SEWERS

City	Date of design	Date of ultimate estimate	Area	Population	Future density	Water supply g.c.d.* as of date of design		Domestic sewage as g.c.d.* as of date of ultimate estimate			
						Domestic	Total	Av. daily normal conditions	Av. daily extreme conditions	Max. rate	Per cent max. rate is of normal
1. Milwaukee	1910	1950	37,790	862,000	22.8	33	98	50	. . .	125	250
2. Detroit	1915	1940	74,500	1,500,000	20.1	110	169	114	. .	228	200
3. Buffalo	1915	1950	24,928	800,000	32.0	81	324	. . .	. .	285	
4. Cincinnati	1913	1950	82,697	711,810	8.6	80–92	131	90	. .	135	150
(a) Mill Creek	1913	1950	52,740	308,664	5.9	. . .	. . .	90	. .	135	150
(b) Ohio River	1913	1950	17,266	303,826	17.6	. . .	. . .	90	. .	135	150
(c) Duck Creek	1913	1950	12,691	99,320	7.8	. . .	. . .	90	. .	135	150
5. Louisville (Beargrass Creek)	1905	. . . .	7,820	230,000	29.4	. . .	. . .	100	. .	200	200
6. Fitchburg	1911	1940	8,134	87,200	10.7	. . .	. . .	75	. .	150	200
7. Toledo	1919	1960	47,300	781,900	16.6	34	92	52	65	118	227
(a) Ten Mile Creek	1919	1960	19,930	312,870	15.7	34	92	52	65	114	220
(b) W. Side and Swan Creek	1919	1960	16,873	304,760	18.1	34	92	52	65	113	218
(c) East Side	1919	1960	10,498	164,270	15.7	34	92	52	65	125	240
‡(d) W. S. Up—River Area	1919	1960	9,037	60,000	6.6	. . .	. . .	52	65	146	281
§(e) E. S. Up—River Area	1919	1960	5,968	50,000	8.4	. . .	. . .	52	65	150	288

TABLE 28.—RELATION OF DOMESTIC, INDUSTRIAL AND COMMERCIAL SEWAGE FLOWS AND GROUND WATER ALLOWANCES USED AS BASES OF DESIGN OF INTERCEPTING SEWERS.—(*Continued*)

City	Industrial sewage					Commercial sewage					Ground water					
	Average rate g.a.d.†	Maximum rate g.a.d.†	Total average flow g.c.d.*	Total maximum flow g.c.d.*	Ratio max. to average, per cent	Average rate g.a.d.†	Maximum rate g.a.d.†	Total average flow g.c.d.*	Total maximum flow g.c.d.*	Ratio max. to average, per cent	Average rate g.a.d.†	Maximum rate g.a.d.†	Average per mile of sewer	Maximum per mile of sewer	Total average flow g.c.d.*	Total maximum flow g.c.d.*
1. Milwaukee	9,350	16,800	36.0	65.0	180	17,700	29,800	20.0	33.0	170	1,200	1,620	......	......	47.5	64.0
2. Detroit	8,000	12,000	25.6	38.4	150	33,000	50,000	15.4	23.4	152	.....	500	......	18,000		
												1,000		36,000		
3. Buffalo	.....	13,000	.....	90.8	......	....	60,000	.....	46.6	......	.....	1,000	.....	25,000	.....	31.4
		16,000										1,850		100,000		
4. Cincinnati	4,500	9,000	51.8	103.5	200	....	40,000	.....	40.5	......	.....	750	......	......	.....	87.0
(*a*) Mill Creek	4,500	9,000	71.5	143.0	200	....	......	.....	.....	......	.....	750	......	......	.....	128.0
(*b*) Ohio River	4,500	9,000	31.0	62.0	200	....	40,000	.....	95.0	......	.....	750	......	......	.....	42.6
(*c*) Duck Creek	4,500	9,000	55.5	111.0	200	....	......	.....	.....	......	.....	750	......	......	.....	96.0
5. Louisville (Beargrass Creek)	.....	24,000	.....	65.0	......	....	30,000	.....	8.6	......	.....	1,960	......	......	.....	66.6
6. Fitchburg	4,444	8,000	64.0	115.0	180	....	......	.....	.....	......	.....	.....	......	......	.....	.....
7. Toledo	8,000	12,000	42.5	63.5	150	15,000	30,000	16.0	32.0	200	.....	.....	22,000 to 30,000	29,000 to 48,000	28.5	38.0
(*a*) Ten Mile Creek	8,000	12,000	23.2	34.8	150	No. area	......	.....	.....	......	600	800	26,000 to 37,000	34,000 to 48,000	37.0	49.0
(*b*) W. Side and Swan Creek	8,000	12,000	37.6	56.5	150	15,000	30,000	37.5	75.0	200	600	800	22,000 to 30,000	29,000 to 39,000	21.0	27.6
(*c*) East Side	8,000	12,000	87.6	131.3	150	15,000	30,000	7.0	14.1	200	600	800	25,000 to 30,000	28,000 to 29,000	26.5	35.4
‡(*d*) W. S. Up—River Area	8,000	12,000	90.0	135.0	150	No. area	......	.....	.....	......	260	320	26,000	32,000	36.0	48.0
§(*e*) E. S. Up—River Area	8,000	12,000	83.5	125.0	150	No. area	......	.....	.....	......	333	410	26,000	32,000	37.0	49.0

* g.c.d. = gallons per capita daily. † g.a.d. = gallons per acre daily.
‡ Included in future West Side and Swan Creek drainage area.
§ Included in future East Side drainage area.
The following notes apply to ground water. 1. Very old sewers. 2. 500 g.a.d. for clay sections, 1000 g.a.d. sandy sections. 3. Sand and clay sections. 4. Clay soil. 7. Tight blue clay soil.

CHAPTER VI

BIOCHEMISTRY OF SEWAGE

SYNOPSIS

1. Definition.—The complex unstable organic substances in human and household wastes soon decompose in the presence of the countless bacteria which enter the sewers with them. This is Nature's arrangement for converting the waste products of Life into simple chemical compounds capable of serving Nature's economy. Such decomposition is inevitable unless prevented by germicides or by refrigeration. It is partly biological and partly chemical and proceeds in varying ways, depending on local conditions. Hydrolysis, biolysis, proteolysis, fermentation, digestion, septicization, putrefaction are terms applied to biochemical decomposition which in some form asserts itself in nearly every branch of the sewage problem.

2. Types.—There are two main types of biochemical decomposition, depending on the presence or absence of atmospheric oxygen, naturally present in bodies of water and necessarily present in filters or activated sludge aerating tanks where oxidation is the object sought. On the other hand where sludge is liquefied or gasified it must be done by decomposition in the absence of oxygen. This is called putrefaction or septicization, as distinguished from the oxidation in streams and filters.

3. Decomposition of Group Substances.—Fats, carbohydrates, such as starches and sugars, proteids and various groups of organic substances found in sewage are subject to quite definite processes in their biochemical decomposition. Ordinarily several groups of bacteria bring about decomposition. Precedence and relative intensity of such processes become complicated by varying local factors, but it is essential to understand the main steps in this process in order to grasp the solution of most sewage problems.[1]

[1] This chapter is devoted to a description of the nature of biochemical processes while quantitative aspects are dealt with in subsequent chapters, particularly Chapters X (Oxygen Balance) and XXI (Septicization and Gasification).

4. Classification of Bacteria.—Bacteria are ordinarily considered as disease or non-disease producing; that is, pathogenic or saprophytic, respectively. But in the biochemistry of sewage the essential feature is that some bacteria grow in the presence and some in the absence of oxygen. These groups are called aerobes and anaerobes, respectively, and are directly related in a causal way with oxidation and reduction (putrefaction), the two main types of biochemical activities as found in sewage problems. Some groups of bacteria can thrive either in the presence or absence of oxygen.

5. Relation to Oxygen.—As stated oxygen is the vitally important basic feature of biochemical changes in sewage and is intimately associated with the type and efficiency of sewage processes and problems as found in practice.

6. Cell Activity and Enzymes.—Sewage decomposition is effected partly by the bacterial cell acting directly on dissolved organic matter and partly by the ferments or enzymes secreted by the cells. It is more important to recognize the two types of activities than to attempt to rate their relative importance.

7. Biochemical Ripening.—In both oxidation and reduction (septicization) processes some days or weeks may elapse before bio-chemical activities reach a normal basis, apparently due to the need of establishing a required quantity of cells or of enzymes or of both.

8. Cycles of Elements.—In the natural purification of streams as well as in many purification processes there is alternate occurrence of oxidizing and reducing types of biochemical decomposition. For this reason it is important to understand that within certain limits several of the organic elements can pass through several steps or cycles which are here described for carbon, nitrogen and sulphur.

DECOMPOSITION OF SEWAGE[1]

As has already been pointed out in previous chapters, the material with which this text deals, namely municipal sewage, is a highly complex mixture of the varied wastes of human activity.

[1] Earle B. Phelps has given in past literature such a clear exposition of many of these facts and hypotheses that we have borrowed liberally therefrom. The reader should consult the following texts by Phelps for elaboration of details: Chapter on the Bacteriology of Sewage, Microbiology, by Charles E. Marshall, 1917; Biochemistry of Sewage, VIII, International Congress Applied Chemistry, XXVI, p. 251.

By the very nature of its origin the groups of material which occur therein are necessarily the resultants of a chance admixture of substances containing chemical compounds and bacterial life of variable origin and characteristics. In the presence of organisms which occur in sewage in great numbers and cover a wide range of typical flora, it is found that in the liquid portion of the medium putrefaction soon sets in and decomposition is the universal phenomenon at almost all stages of its history. It is inevitable that such a material as sewage, made up of highly active biological forms with an ample and unstable food supply, should proceed along the lines of chemical change, characteristic of all forms of organic substances. The essential characteristics of such conversion of materials are that it is partly biological and partly chemical in its nature and that it proceeds in different ways depending upon the nature and quantity of bacterial forms and of organic materials present in the sewage.

Such a complex organic medium, seething with microscopic life, will naturally go rapidly through a process which is similar to the universal decay of all organic subtances with which we are familiar. Practically every known waste material in this universe is or may be convertible into substances of a simpler or more complex chemical nature. Familiar examples of this phenomenon surround us on all sides. The only difference, for example, between the gradual deterioration, decomposition or destruction of a piece of wood and that which goes on in the case of sewage is in the rate of such change and in the characteristics which appear during the process.

In the case of sewage the process of decay is taken advantage of so as to convert a material which, because of its lack of stability and because of its high rate of decomposition, gives rise to objectionable decomposition products. We take advantage of this decomposition process to convert objectionable and unstable organic waste materials of life processes into stable and relatively harmless mineral forms. In this process of conversion both biological and chemical forces are intermingled and are productive of the results to be accomplished.

It was once believed that these changes in material were almost entirely due to chemical processes. The actual facts of organic change of sewage, however, in recent years cannot be explained by purely chemical phenomena. For example, heat, refrigeration, germicides or preservatives may postpone or interrupt

permanently the processes of decomposition. Therefore, an essential factor in the conversion of organic substances of sewage is the presence of bacteria. The chemical changes produced are only indices or results of the performance of these minute organisms. The changes brought about are the result of the destruction of organic materials by these countless organisms in their search for and in their consumption of food. The speed with which sewage is converted may therefore be explained, in contrast with the changes which take place in a more stable material such as wood, as due to the existence of a satisfactory food supply in such condition as to be easily available for the development and progress of the biological world resident therein.

The process of decomposition is thus primarily one of consumption of decomposable substances by biological forms, principally bacteria, which render such substances non-decomposable or more stable than originally. Furthermore, inasmuch as the process is obviously dependent upon the existence of food supply, chemical in nature, and a group of biological forms which may thrive upon such an available food supply, we designate the joint process in its entirety as the biochemical conversion of sewage, so as to take cognizance both of the chemical and of the biological features regulating the phenomenon.

In the processes of biochemical change, classification is based upon the change accomplished rather than upon the particular species of bacteria which may accomplish such changes. In other words, biological decomposition of sewage is designated by the terms hydrolysis, biolysis, proteolysis, fermentation, digestion, septicization and putrefaction, in accordance with the kind of change which is accomplished in the sewage, rather than by the nature or classification of the type of organism which has brought it about. Similarly each of these terms designates biochemical changes associated with all of the processes familiar to us, which have for their purpose the conversion of sewage into more stable and less objectionable substances.

Types of Biochemical Changes

The general character of changes which may be brought about in sewage may be of two types, depending upon whether the results are accomplished by one or the other of two major groups of sewage bacteria, classified usually as the aerobic or oxidizing bacteria and the anaerobic or putrefactive bacteria.

In the aerobic reactions, the presence of oxygen is essential in order to provide for the growth and metabolism of groups of organisms which have the characteristic of surviving and performing most satisfactorily in the presence of atmospheric oxygen. The oxidizing processes are those which are characteristic of most of our purification processes such as trickling filters and the activated sludge aeration process. The oxidizing reactions are distinguished by the fact that oxygen is added to the molecule with the result that the end products of change always contain more oxygen than the initial substances. The end products are, in general, carbon dioxide, water and nitrates, in contrast with the end products of anaerobic changes, which are usually methane, hydrogen, nitrogen and ammonia.

The anaerobic or putrefactive changes are the results of the decomposition of sewage in the absence or relative absence of atmospheric oxygen by groups of bacteria which function best in a medium relatively free from oxygen. In contrast with aerobic processes, anaerobic changes involve the abstraction of oxygen from complex molecules and its transfer to simpler compounds. It is unimportant to attempt to define this process by some exact term or to argue about the exact definition of the common term putrefaction, which is assigned to a description of these particular anaerobic changes. For present purposes we merely assume that putrefaction and anaerobic changes in organic matter are, for practical purposes, virtually synonymous. Advantage is taken of a number of this group of changes, as of the aerobic group, in practical processes of sewage conversion such as the decomposition of sludge by liquefaction or gasification. Both of the latter occur in the absence of oxygen, which distinguishes this process from the oxidation changes which take place in streams and in trickling filters.

Decomposition of Group Substances

It is interesting to point out, in the further elaboration of the description of these processes, that organic substances are found in sewage which usually pass through definite changes in their biochemical decomposition. In these changes ordinarily several varieties of bacteria may be at work. Likewise experience has shown that the direction which such changes may take, the intensity of the conversion and the precedence of one type of change over another are all dependent upon the predominating

type of bacterial activity, which varies with such local factors, as character of water supply, temperature, presence of various compounds and the stage at which such processes are under scrutiny. A discussion of several types of biochemical decomposition of such groups is helpful in clarifying these problems.

Changes in Carbohydrate.—The soluble portions of organic matter are the first to be attacked by bacteria. Representative of this group of substances are the sugars and starches, which are excellent nutrient substances for bacteria and are decomposed quickly. The insoluble carbohydrates, such as cellulose, are attacked only after prolonged periods of digestion under ordinary conditions. These will be discussed later.

Changes in Protein.—One of the most frequent phenomena confronting the observer of bacterial activity in sewage disposal problems is the changing of organic substances so as to convert them from solid or semi-solid to liquid form. This particular process we call liquefaction. It describes broadly all of the biochemical changes by which solid and insoluble organic material is converted into compounds of soluble nature. One of the principal characteristics, for example, of protein liquefaction is the production of an increased solubility of the conversion products. Our knowledge of the exact process and of the exact reactions which accompany the change of complex albuminous substances to simpler soluble compounds is quite limited. We know that an enormous variety of bacteria can accomplish this liquefaction of protein along lines somewhat resembling that which takes place in ordinary gastric digestion.

It suffices to say definitely of the liquefaction of protein that the reactions result in the simultaneous production at various states of albumoses, peptones, amino acids, amines, ammonia and carbon dioxide, with a continuous and permanent tendency toward simpler and more soluble side products.

Changes in Cellulose.—In the case of cellulose, as with protein materials, anaerobic processes of conversion predominate. Here again the organisms operate so as to produce fairly rapid fermentation of the cellulose with the chief products, carbon dioxide and methane. The detailed factors and the quantitative results involved in this process are discussed at greater length in Chapter XXI. From the chemical standpoint, the fermentation of cellulose is hydrolytic in nature, and bacteriologically it is probably also the resultant of a large group of organisms working jointly

with each other towards the ultimate conversion or destruction of cellulose material as such. Although many specific organisms have been described as responsible for the fermentation of cellulose, it is probable that the bulk of the changes occur as the result of processes going on in a complicated biological world as side products of other changes accompanying it.

Changes in Fats.—Of the objectionable contents present in sewage, in the way of interfering with the normal process of decomposition, fats and soaps are among the most difficult to convert. Although there is a gradual, slow chemical and physical change of fats in sewage, through which the fat may eventually lose its identity, it still remains a fact that much of the heavy scum which appears in sewage tanks for settling and for digestion of sewage solids is undoubtedly due to the fatty materials which have escaped much disintegration.

Here again evidence seems to point to the fact that the conversion of fats is the resultant of the activity of a group of organisms rather than of one particular kind. In the changes which fats undergo, simpler end products result, although the saponification and emulsification of fatty particles is usually a long and difficult process.

Changes in Urea.—A typical case of decomposition is indicated in the fermentation of urea. A large number of bacteria of almost universal occurrence have the power of producing fermentation of urea with the production of ammonia. So simple and so prompt are these changes that in many instances the change from urea to ammonia takes place in the collecting system with the result that the ultimate conversion of urea to some simple compounds does not involve a problem of particular practical importance.

Reduction of Sulphates and Nitrates.—Although the production of hydrogen sulphide may be accomplished in the anaerobic decomposition of sewage, it frequently happens that the amount of such hydrogen sulphide is inappreciable. It may arise through the splitting off of sulphur from many protein substances or it may be the resultant of the decomposition of sulphates normally present in many sewages. Hydrogen sulphide usually combines with small amounts of iron present in sewage, particularly with combined sewerage systems, due to street wash.

There are some outstanding examples of special sewages where the amount of hydrogen sulphide produced may reach

considerable proportions due to the anaerobic decomposition of mineral sulphates originally present in the public water supply or in particular industrial wastes which reach the sewers. An interesting example of the extent to which hydrogen sulphide may be formed is that of the Decatur, Ill., sewage which may produce a gas containing as much as 1 per cent of hydrogen sulphide due to the large proportion of wastes incident to starch manufacture, which the sewage normally carries. In a similar fashion there are examples of municipal sewage containing excessive amounts of mineral sulphate which are productive of excessive hydrogen sulphide in decomposition processes.

The reduction of nitrates and possibly of phosphates is analogous to that of sulphates. The principles involved are the same and it should be emphasized once again that the phenomena are characteristic of bacteria of many forms, rather than of a particular form or species.

Classification of Bacteria

Bacteria, the lowest scale members of the vegetable kingdom, are micro-organisms of unicellular structure. Their importance in this discussion comes from their being Nature's most important scavengers. We may classify bacteria as producing or not producing disease. The first group are usually termed pathogenic, while the second are called saprophytic. The saprophytic bacteria comprise the normal forms found in air, water, soil, decomposing food and organic material generally. The pathogenic forms are typified by the bacilli of typhoid fever, dysentery, cholera, tuberculosis, etc. Inasmuch as the pathogenic bacteria do not easily thrive outside the animal body and in nature diminish with more or less rapidity due to unfavorable environmental factors, particularly temperature, restricted food supply and antagonism of other bacteria, we shall not devote any further discussion to this group. So far as sewage disposal is concerned, the significance of pathogenes lies in the adoption of procedures which lead to their more prompt destruction or to their elimination from adjacent water intakes.

The non-disease producing bacteria, on the other hand, are of established importance in the subject at hand, because they are instrumental in the decomposition of organic matter and in its transformation to more stable organic and inorganic substances.

It is pertinent, therefore, to indicate briefly what the factors are that regulate the growth, life and performance of this particular group of organisms.

Bacteria display an astonishing diversity in their physiology and in their food requirements. In the presence of abundant moisture they attack almost all forms of complex organic substances. There are varieties of bacteria that attack simpler non-protein substances, while other groups exist mainly on simple inorganic material. In sewage there are, of course, many organic substances which furnish suitable material for food to a very large number of bacterial species.

As with all other forms of life, temperature plays an important role in the growth of bacteria. The bacteria generally concerned in sewage decomposition thrive at the lower temperatures commonly found in sewage and water. By suppressing certain species of bacteria and encouraging others, the influence of temperature on the rate and character of decomposition is a highly important one.

Again, as in all other life processes, the degree of acidity or alkalinity of the medium in which bacteria live exerts a marked influence on their group activity, in that it regulates the types of organisms which develop and thus influences the nature and rate of decomposition. Similarly certain chemicals added to or originally present in sewage may inhibit growth or bring about complete destruction of bacterial life. One of the increasing problems of artificial purification of sewage is the interference with the normal biological processes through the legal or surreptitious addition to sewage of strong acids or caustics, metallic salts or coal tar by products in industrial wastes.

Relation to Oxygen.—The adaptation of bacteria to dissolved atmospheric oxygen has for many years served as one of the important bases for differentiation of bacterial forms. Many of the bacteria known to us may with difficulty survive in the absence of atmospheric oxygen. These bacteria for which oxygen is a necessity of development are known as aerobic or "aerobes." There is a similar group of organisms which may thrive in either the presence or the absence of oxygen. They derive their name from this adaptation and are designated as "facultative anaerobes." Bacteria unable to grow except in the substantial absence of oxygen are known as "obligate anaerobes."

The preservation and successful regulation of aerobic conditions in certain sewage purification processes mean the difference between successful performance of plant and failure. As pointed out earlier in this chapter, such units as trickling filters and activated sludge aeration tanks are largely dependent upon the establishment and maintenance of aerobic conditions for biochemical change, whereas adequate sludge digestion, involving liquefaction or gasification, or both, is likewise conditioned by the establishment and regulation of an anaerobic state.

Cell Activity and Enzymes.—Decomposition of sewage proceeds not as a single step, but as a succession of steps in which may be concerned the activities of many species of bacteria having different physiological functions. Where the activities of two or more species are mutually helpful, the action is referred to as "symbiosis." Where the benefit is one sided, as in the case of a succession of species, the action is known as "metabiosis."

In the presence of abundant food material there is always a definite limit to bacterial activity on account of the accumulation of poisonous products of metabolism, even where a single species is present. Where several species are growing together, the products from one frequently influence unfavorably the growth of another bacterial species. This is known as "antibiosis" or "bacterial antagonism." It has a very great importance in a practical way in all biological processes.

Mention might be made here of the very definite power which is possessed by certain old bacterial cultures of destroying and dissolving other bacteria. This "lysis" or bacteriolytic power is known as the "bacteriophage phenomenon" and is attributed by D'Herelle, its chief exponent, to the activity of an ultramicroscopic living organism developing at the expense of the bacteria. Bacteriologists are not in agreement as to the nature of the bacteriophage which exhibits some properties not readily explained by enzyme action.

Bacteria are able to utilize directly as food only soluble substances capable of being absorbed through the cell wall. However, it is well established that one activity of many bacteria is the production of soluble ferments called "enzymes" which diffuse from the cell into the surrounding medium and thereby suspended organic matter is liquefied or gasified and made into an assimilable form. The utilization of solid organic material by bacteria is thus similar to the processes of animal digestion

by which food is rendered available for absorption, through the action of enzymes produced as internal secretions. In fact, some of the bacterial enzymes perform identical functions with enzymes of animal origin, as for instance rennet.

As bacteria are able to decompose practically all kinds of organic material, it is not surprising that the number of specific enzymes found in bacterial cultures is quite large and concerned with a variety of activities, such as breaking down of fats, splitting of sugars, hydrolysis of proteids, hydrolysis of cellulose, various oxidation and reduction changes, release of gases, etc. Specific enzymes have been isolated from raw sewage and from various sewage treatment processes.

Cycle of Changes

When one deals with as complicated reactions as have been indicated so far, it is obvious that all of the elements entering into the constitution of organic matter may enter into the composition of new substances, depending upon the particular set of circumstances under which any of these changes may be brought about. In all processes of nature it is obvious that none of these substances are permanently wasted or removed from living activities. All of the elements with which we are familiar are used over and over again. This rotation, circulation or cycle of elements is characteristic of much of the organic material with which we have to deal. We are confronted with changes in both directions from the complex to the simple and from the simple to the complex in the case of all materials available. For example, the carbon in organic material on decomposition reappears as methane, carbon dioxide and inorganic bicarbonates. In a similar way oxygen combines with other elements to form carbon dioxide, water, nitrates, carbonates, sulphates, phosphates, etc. The important fact is that in the economy of Nature all that happens in biochemical sewage conversion is the breaking down of complex forms into simple units which in turn are synthesized at a later date into a more complex organic material by plant and animal life. In this way the cycle of conversion is continually repeating itself in nature. The interesting fact of the entire problem is that some degree of uniformity of change occurs at all times in a world of compounds and biological forms so complex and so intermingled with antagonistic organisms as is to be found in sewage. An understanding of these cycles may

be better obtained by referring in some greater detail to two elements of more than ordinary importance in sewage and sewage purification. These are nitrogen and sulphur. The steps or cycles through which carbon may pass have already been indicated above.

Nitrogen Cycle.—The element nitrogen passes through a variety of compounds in so far as its relation to nature is concerned. These changes comprise what is generally designated as a nitrogen cycle. It merely refers to the sequence in which living plants utilize the inorganic nitrogen to produce plant proteins, which in

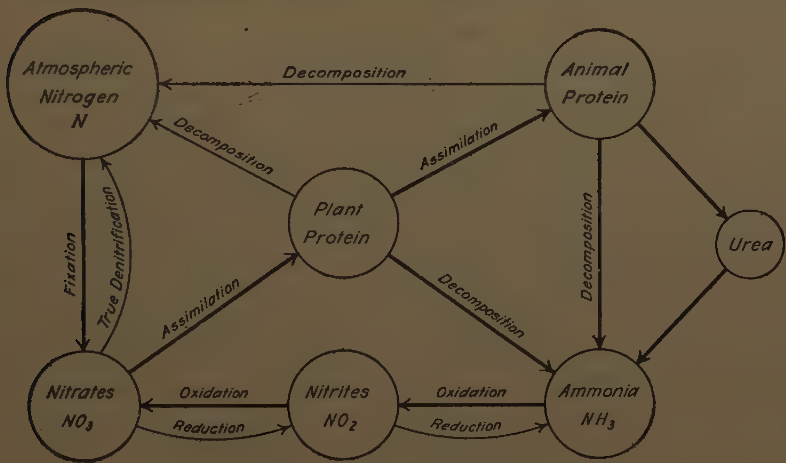


FIG. 1.—Graphic representation of nitrogen cycle.

turn are utilized by animals, converted into animal proteins and then subjected to decomposition processes resulting in inorganic nitrogen, which again becomes available for plant food. These interrelations and conversions in the nitrogen cycle are perhaps more clearly shown graphically in Fig. 1.

In the sewage problem, of course, we are generally concerned with that portion of the nitrogen cycle which relates to the decomposition of animal and plant products and their conversion to nitrates. Some renewed interest is being shown in addition in the feasibility of utilization of end products of sewage decomposition as agricultural fertilizer. The breaking down of protein molecules referred to earlier in this chapter takes place in successive steps with the intermediate production of ammonia which is converted to nitrites and then nitrates as the final stage.

While these processes leading toward greater stability of sewage substances are at work, other bacteria may be reducing nitrates and nitrites under anaerobic conditions in the effort to obtain their necessary oxygen not otherwise available. In this fashion nitrates may be reduced to nitrites, free ammonia and nitrogen.

Sulphur Cycle.—Mineral sulphates in the soil are utilized by higher plants. They are elaborated into plant protein which in turn is assimilated into animal proteins. Decomposition of plant and animal protein takes place with the production of simpler sulphur compounds. On oxidation these again return to original sulphate form. Sulphur may occur in sewage both as animal protein or as inorganic sulphates contained in the public water supply or ground water leakage into sewers or disposal plants.

We are concerned in sewage problems with the compounds of sulphur because of the production of objectionable odors due either to hydrogen sulphide or to more complex sulphur organic compounds and because of the part which sulphur acids may play in the disintegration of concrete and masonry structures.

CHAPTER VII

LIMITATIONS OF DILUTION METHOD: NUISANCE ASPECTS

SYNOPSIS

1. Extent of Use.—Disposal of sewage by dilution in a convenient neighboring watercourse was the universal custom for many years following the adoption of the water carriage system for the removal of household wastes. Eighty-two per cent of the population resident in cities of the United States, having a population of more than 100,000 based on the 1920 census, made use in 1924 of the dilution method alone or aided by fine screen plants in a few instances.

2. Shortcomings.—Nuisances due to conditions offensive to sight and smell are numerous in watercourses receiving sewage. Still more serious are those hygienic aspects of dilution involving damage to water supplies, shellfish layings and bathing beaches. These are discussed in a later chapter, as this chapter is confined to nuisances not directly related to public health.

3. Inadequate Mixing.—Serious faults existed in the methods for delivering sewage into watercourses. Mixing with diluting water was inadequate and frequently sewer outlets terminated above the high water mark with resultant stranding of sewage solids on exposed beaches above the low water line.

4. Separation of Solids.—Even where dispersion of the sewage in diluting water was reasonably provided for, there are many instances where objectionable conditions arose, either through floating solids on the watercourse or objectionable deposits of sewage mud on the bottom of the watercourse.

5. Movement of Solids.—Velocities of flow of the diluting water are an important element. Where adequate they may prevent the accumulation of objectionable sludge deposits, although in some instances currents may move the pollution to other points where objectionable conditions may arise.

6. Local Factors.—To state where to draw the line as to the relation between the volume of sewage and diluting water in

which it may be discharged without nuisance is not a simple matter. The relation depends upon the velocities of flow in the diluting water, the dissolved oxygen in the diluting water, the provisions to prevent marginal pollution, the effect of pollution of the diluting water above and below the point of discharge from the particular sewer outlet under investigation, the temperature of the polluted water prior to its diluting ratio being increased by contact with additional volumes of water, and the time available.

7. Oxygen Requirements.—So long as some oxygen surrounds all sewage matters, anaerobic decomposition with its foul odors is not a factor of importance. Sewage mud or decomposing solids in shallow water may give trouble, however, under some circumstances. Decomposing organic matters in sewage reduce the oxygen in the diluting water and complications sometimes arise through the reduction of dissolved oxygen to such a point as to interfere with major fish life, although no serious nuisances arise.

8. Dilution Ratio.—A dilution of 4 to 7 cubic feet per second is generally required for the sewage for each 1000 of population connected with the sewers. This wide range seems inevitable due to variations in local conditions, such as nature of diluting water; the occurrence of industrial wastes, if any; the deposition of solids; and the nature of the receiving body of water and its biologic history. Subject to limitations within the ranges above stated, the dilution method gives reasonable service for a great many municipalities. Suitable examples of the dilution method could still further be increased by correction of faulty technique as to discharge of the sewage into the diluting water. In some instances, the dilution method may be used without nuisance, if objectionable floating and settleable solids are removed by partial treatment of the sewage.

9. Purification Sometimes Needed.—In some cases, however, the limitations are so pronounced, particularly where the diluting water becomes relatively scarce and inadequate at certain seasons of the year, that it is essential to subject the sewage to substantial purification before dilution in the receiving stream.

10. Present Status.—The dilution method generally prevails in the United States where there are many large rivers. In some cases corrections are relatively simple; in others, considerable improvement in the sewage is required before discharge

into the stream; and, in still other instances, the limitations in the method are such that there is no other way to proceed than by first subjecting the sewage to substantial purification. In summary, the dilution method is a logical disposal procedure, the appropriate use of which requires as careful study as any other method.

EXTENT OF USE OF DILUTION

Disposal of sewage by dilution is the prevailing method for large American cities as shown by Table 29. It is almost universal for conditions where no gross nuisances result, or where in case of new works no nuisances are likely to arise, judged by experiences elsewhere.

Indeed, the existence of nuisances has not been sufficient to prompt the correction of flagrant instances of the over-taxing of the diluting power of streams which receive sewage. To a greater extent than most people realize, active or prospective litigation has prompted communities to adopt sewage treatment works.

In early years the expense of treatment works was considered burdensome for many localities. More recently during the development of the so-called biological processes, cities have proceeded with care in the hope of more suitable methods becoming available at less cost. This has been true even in those states where public health laws provide for the elimination of objectionable sewage pollution.

The present status of sewage disposal by dilution is not definitely settled. It is generally recognized by those concerned therewith that it has an indisputable field of usefulness, but that much more care must be taken in its utilization than has been generally the case hitherto. Obviously, there are cases where purification is required, but it by no means follows that this should be the practice universally. What are the conditions, therefore, for the suitable use of this method and where do the limits arise in its applicability?

TABLE 29.*—SEWAGE DISPOSAL METHODS IN THE YEAR 1926 OF ALL CITIES IN THE UNITED STATES HAVING A POPULATION OF 100,000 OR MORE IN 1920

City	Populations of cities in 1920—sewage disposal in 1926 by		
	Dilution only[a]	Tank treatment only	Complete treatment[b]
New York	5,620,048		
Chicago	2,501,705	150,000	50,000
Philadelphia	1,598,779	225,000	small
Detroit	993,678		
Cleveland	596,841	200,000	†
St. Louis	772,897		
Boston	748,060		
Baltimore	....	....	733,826
Pittsburgh	588,343		
Los Angeles	576,673		
Buffalo	506,775		
San Francisco	506,676		
Milwaukee	....	....	457,147
Washington, D. C.	437,571		
Newark	....	414,524	
Cincinnati	401,247		
New Orleans	387,219		
Minneapolis	380,582		
Kansas City, Mo.	324,410		
Seattle	315,312		
Indianapolis	....	....	314,194
Jersey City	298,103		
Rochester	....	285,700	10,000
Portland, Ore.	258,288		
Denver	256,491		
Toledo	243,164		
Providence	.....	237,595[c]	
Columbus	....	....	237,031[d]
Louisville	234,891		
St. Paul	234,698		
Oakland	216,261		
Akron	168,435	....	40,000
Atlanta	....	....	200,616
Omaha	191,601		
Worcester	....	....	179,754
Birmingham	....	....	178,806
Richmond	171,667		
Syracuse	....	171,717	

TABLE 29.—SEWAGE DISPOSAL METHODS.—(*Continued*)

City	Populations of cities in 1920—sewage disposal in 1926 by		
	Dilution only[a]	Tank treatment only	Complete treatment[b]
New Haven	162,537		
Memphis	162,351		
San Antonio	....	....	161,379[e]
Dallas	....	158,976	
Dayton	152,559		
Bridgeport	143,555		
Houston	....	....	138,276
Hartford	138,036		
Scranton	137,783		
Grand Rapids	137,634		
Paterson	....	135,875	
Youngstown	132,358		
Springfield, Mass	129,614		
Des Moines	126,468		
New Bedford	121,217		
Fall River	120,485		
Trenton	119,289	under construction	
Nashville	118,342		
Salt Lake City	118,110		
Camden, N. J	116,309		
Norfolk	115,777		
Albany	....	113,344	
Lowell	112,759		
Wilmington	110,168		
Cambridge	109,694		
Reading, Pa	....	....	107,784
Fort Worth	....	....	106,482
Spokane	104,437		
Kansas City, Kan	101,177		
Yonkers	100,176		
Total	22,421,250	2,092,731	2,915,295
Percentage	82	7	11

* From Part III, Appendix I on Sewage Disposal of the Report of the Engineering Board of Review of the Sanitary District of Chicago, February 21, 1925. Corrected to date.

† Southerly trickling filter plant to serve 240,000 now under construction.

[a] Fine screening in a few cases.

[b] Removal of settling solids and oxidation.

[c] Chemical precipitation.

[d] Part of year only, by dilution in winter months.

[e] Broad irrigation at least part of the year.

PARTIAL RELIANCE ON DILUTION

It is a long step in point of expense from dilution alone to fairly complete purification. Partial purification in conjunction with well-arranged dilution will serve many a problem well for some years, and permit progressive adoption of purification works as required. The British authorities frequently require comprehensive plans for fairly complete purification, but permit a "relaxation" from full standard requirements where conditions are suitable for taking substantial advantage of dilution for a term of years.

These and other matters relating to corrective measures will be dealt with in Chapter XIII, but are mentioned here to facilitate appreciation of the factors discussed with reference to limitations of the dilution method.

USE OF DILUTION WITHOUT NUISANCE

The disposal of sewage by dilution is suitable when, by dispersion in water, the impurities are disposed of without nuisance or menace to health.

Unquestionably there are many cases where sewage disposal by dilution is followed by self-purification of the diluting water to the extent that all reasonable sanitary requirements are met. On the other hand, there are many locations where this method is not suitable at all times unless the sewage is given some form of treatment, varying with local conditions as to degree and cost.

Although there are no hard and fast rules of procedure, it is helpful to explain the leading evidence on the subject. Particular attention should be given to the following points:

1. The diluting water should show no signs of floating matters offensive to the eye, or likely to become stranded upon margins of the stream.

2. Coarse solid matters, if need be, should be removed, so that in the diluting water there will not be formed, near sewer outlets or at shallow places, or in front of dams, objectionable banks of sludge or sewage solids. Where the stream is deep and has a good current at all times, as in the lower Mississippi, this element is not much of a factor. On the other hand, deposited sewage mud is a conspicuous cause of offense in many streams which could be kept in satisfactory condition if solids were

removed from the sewage. The same may be said of some ferry slips.

3. Ranges in the velocity of flow of the diluting water are of much practical significance. If the velocity is always high enough to prevent substantial deposits of sewage mud or sludge, it is of great aid to the efficient operation of the dilution method. If scouring velocities ordinarily prevail at sufficiently frequent intervals to prevent seriously offensive results from decomposition of sludge, much benefit is also secured from stream velocity. But if depositing velocities normally prevail for weeks and months at a time, the decomposition of sewage mud needs much careful attention, depending upon the depth and frequency of change of the over-lying water. In some cases such velocities permit thoroughly satisfactory results only in connection with the removal of settleable solids from the sewage or dredging sludge from the bed or banks of the body of water into which the sewage is discharged. Dams which reduce the velocity of flow for long periods at a time aid in the clarification of streams receiving raw sewage; but the sewage sludge frequently decomposes so as to add materially to complication from offensive odors and the deoxygenation of the overlying water.

4. The dispersion of the sewage in the diluting water should be such that the sewage undergoes bacterial decomposition on an aerobic basis. In other words, a safe margin should be maintained for guarding against anaerobic decomposition with its foul odors. This applies specifically to the degree of dilution which will be touched upon later in this chapter.

5. In providing for a safe margin in the dissolved oxygen content of the diluting water, consideration should be given to a residual of oxygen sufficient for reasonable requirements of major fish life, if local conditions make that important.

6. Trade wastes are liable to prove injurious to bacteria and other forms of life and upset estimates which otherwise are based on sound records of experience elsewhere. In many streams they do far more mischief than does domestic sewage. In all manufacturing valleys they require special study.

7. Temperature and time are important elements in studying the deoxygenation of a stream by the sewage which enters it. In practice this factor is of more importance than hitherto considered. It should be studied with respect to the duration of flow from the point of initial pollution to lower points where there

is either added pollution by sewage or additional dilution from incoming streams, or both. The combined effect of all such factors needs due consideration.

8. Much care should be given to the influence which disease germs of sewage origin may have on neighboring water supplies, bathing beaches or shellfish layings. This involves questions of sanitary and business policy as well as of local orders and statute laws.

FACTORS INVOLVED

Dilution is just as real a method of disposal of sewage as by a treatment plant. Technically it is perhaps more complicated in its adaptation to some problems, but ordinarily it involves works which in comparison with those of artificial construction are simpler and cheaper both to build and operate.

It should not be inferred that because a method has been crudely and unsatisfactorily applied in the past, for economical or other reasons, it is not worthy of the most careful study.

The dilution method involves consideration of the following processes and factors:

(*a*) Flotation.

(*b*) Sedimentation.

(*c*) Food supply with respect to grosser micro-organisms which in turn serve as food supply for fish.

(*d*) Aerobic and anaerobic decomposition of sewage by means of the bacteria.

(*e*) Maintenance of a proper "oxygen balance" throughout the entire body of diluting water.

(*f*) Consideration of "residual oxygen" in the diluting water in relation to requirements of major fish life.

(*g*) Bacterial removal with respect to longevity or rate of dying off of disease germs, and their deposition in the stream, during the period of transit from the point of entrance to the location of neighboring water supply intakes, bathing beaches or shellfish layings.

DILUTION NECESSARY TO PREVENT NUISANCES

When the Chicago Drainage Canal project was investigated in 1887, Hering, Williams and Artingstall recommended a degree of dilution equivalent to 4 cubic feet of lake water per second to be discharged into the canal for each 1000 of population connected

with the sewers. In the course of legislative hearings required for the enactment of proper laws, this dilution was reduced to 3.33 cubic feet per second as a minimum.

The results of earlier experiences at that period suggested that inoffensive results would be obtained if the dilution per thousand population ranged from 2 to 3.3 cubic feet per second of minimum flow. That information was probably complicated somewhat by assumption as to the actual number of persons in the city connected with the sewer system, and in some measure probably with the assumption that sewage solids would be deposited immediately below the location of the town discharging the sewage, and would be removed by dredging.

The Chicago ratio actually adopted has attracted much attention, notwithstanding that it is too low under actual local conditions. These local conditions require consideration to be given to the fact that the stockyards and packing town wastes are equivalent in organic matter to the sewage of more than 1,500,000 people. Secondly, disposal by dilution at Chicago and down the Illinois River is complicated by the fact that in the summer the canal and river are deoxygenated by the sludge deposited during preceding months of the year.

Stearns estimated that, under Massachusetts conditions, local factors caused the needed degree of dilution to fall within the range of from 2.5 to 7 cubic feet per second per thousand population.

Hazen in 1898 reported to the Ohio State Board of Health a range of diluting factors from 1.5 to 10 cubic feet per second per thousand population. The higher limit included sluggish streams and those already somewhat polluted.

Goodnough in later reports of the Massachusetts State Board of Health has stated, from observing Massachusetts streams, that objectionable conditions were found in all cases where the stream flow was less than 3.5 cubic feet per second per thousand population connected with the sewers and that conditions were not likely to be objectionable where the dilution exceeded 6 cubic feet.

The above data are the general guides used by engineers in connection with inland streams. Their utility is closely associated with factors of trade wastes and existing decomposing sludge deposits which require serious attention in the consideration of problems of this sort.

Where sewage is free from settleable solids, the diluting factor is taken by some engineers at 2 to 2.5 cubic feet per second per thousand population. This makes little or no allowance for trade wastes or past accumulations of sludge still remaining on the stream beds.

APPEARANCE

A dilution of 4 cubic feet per second per thousand population is equivalent to saying that the sewage of one person per day would on an average be diluted to 2585 gallons. This corresponds with a dilution of about 25 times for sewage of ordinary strength, say 100 gallons per person daily. After sedimentation it is found that ordinary American sewages contain a range of from about 50 to 100 parts per million of non-settleable solids. When uniformly dispersed in 25 volumes of river water, there would be no objectionable turbidity due to the sewage. It could not be detected by the eye. Indeed it could scarcely be detected by laboratory methods used for turbid or colored streams.

It is also to be pointed out that with the turbid waters of the South and West a reasonable dilution factor leaves no room for complications as to unsightly appearance of diluted sewage. The normal turbidity of those streams is such that 2 to 4 parts per million of non-settleable solids do not appreciably increase the turbidity.

CONCLUSIONS OF ROYAL COMMISSIONS ON SEWAGE DISPOSAL

In England where the rivers are generally small, and the population resident on the watersheds is comparatively great, it is of interest to note that in 1912, after some 14 years of deliberations, the Royal Commission summed up its conclusions as follows:

(*a*) The law should be altered so that a person discharging sewage matter into a stream shall not be deemed to have committed an offense under the Rivers Pollution Prevention Act, 1876, if the sewage matter is discharged in a form which satisfies the requirements of the prescribed standard.

(*b*) The standard should be either the general standard or a special standard which will be higher or lower than the general standard as local circumstances require or permit.

(*c*) An effluent in order to comply with the general standard must not contain as discharged more than 3 parts per 100,000 of suspended matter, and with its suspended matters included must not take up at 65° F. (18.3° C.) more than 2.0 parts per 100,000 of dissolved oxygen in 5 days. This general standard should be prescribed either by Statute or by order of the Central Authority, and should be subject to modifications by that Authority after an interval of not less than 10 years.

(*d*) In fixing any special standard the dilution afforded by the stream is the chief factor to be considered. If the dilution is very low it may be necessary for the Central Authority, either on their own initiative or on application by the Rivers Board, to prescribe a specially stringent standard, which should also remain in force for a period of not less than 10 years.

(*e*) If the dilution is very great the standard may, with the approval of the Central Authority, be relaxed or suspended altogether. Our experience leads us to think that as a general rule, if the dilution, while not falling below 150 volumes, does not exceed 300, the dissolved oxygen absorption test may be omitted, and the standard for suspended solids fixed at 6 parts per 100,000. To comply with this test no treatment beyond chemical precipitation would ordinarily be needed. If the dilution while not falling below 300 volumes does not exceed 500 the standard for suspended solids may be further relaxed to 15 parts per 100,000. For this purpose tank treatment without chemicals would generally suffice if the tanks were properly worked and regularly cleansed. These relaxed standards should be subject to revision at periods to be fixed by the Central Authority, and the periods should be shorter than those prescribed for the general or for the more stringent standards.

(*f*) With a dilution of over 500 volumes all tests might be dispensed with, and crude sewage discharged subject to such conditions as to the provision of screens or detritus tanks as might appear necessary to the Central Authority.

In effect, the above conclusions recognize the propriety of taking advantage of diluting water where available in suitable quantities. The biochemical oxygen demand is made to apply where necessary with relaxation wherever appropriate.

In comparing the dilutions of English sewage, it should be borne in mind that the sewage is much stronger than that found in America, the volume usually ranging from 30 to 40 U. S. gallons per capita per day, or say 35,000 gallons per day per thousand population. Thus, a dilution of 150 volumes would correspond roughly to about 8 cubic feet per second per thousand population as the limiting point where the biochemical oxygen demand test may be omitted.

CHAPTER VIII

HYGIENIC ASPECTS

SYNOPSIS

1. Disease Germs in Sewage.—Sewage bacteria frequently include germs of typhoid fever, Asiatic cholera and diarrhea. Sewage polluted water supplies, if not adequately purified, will sooner or later cause an unusual prevalence of some of these diseases of intestinal origin.

2. Epidemic from Infected Water Supplies.—Water-borne epidemics in various parts of the world have occurred in such numbers that it is unnecessary to repeat here details which are readily available elsewhere to public health workers. It is worth recalling, however, that the severe epidemics of Asiatic cholera in Hamburg in 1892–3 probably taught a lesson unequaled by any other experience in the field of municipal sanitation. It did more than any other event to spread the knowledge of the germ theory of disease and the importance of various steps related thereto.

3. Longevity of Disease Germs in Water.—Typhoid bacteria die quite rapidly in ordinary waters and so far as known never multiply in natural waters. In a few days a majority of the bacteria will die and in a week or two much more than 90 per cent will ordinarily have disappeared. A small number of resistant typhoid fever bacilli will live, however, for weeks or months. The germs of Asiatic cholera seem to behave in a manner quite similar to those of typhoid fever, although information about them is less definite.

4. Shellfish Pollution.—Shellfish taken from sewage polluted waters may transmit water-borne diseases, as all of the specific germs are often not killed by ordinary methods of cooking oysters and clams. Where shellfish are eaten raw, as is frequently the case, this danger is enhanced.

5. Control of Shellfish.—Some of the states along the Atlantic coast have prohibited the sale of shellfish from certain polluted sources. Some states issue certificates for shellfish laying which

are in satisfactory sanitary condition. There are no commonly accepted standards by which to judge shellfish layings, and uncertainty obtains relative to beds that are not above suspicion, but which are not grossly polluted. More recently, many states and some Canadian provinces require certification of layings by either individual states or by the United States Public Health Service.

HYGIENIC ASPECTS

Since sewage contains important groups of excremental bacteria capable of causing disease when ingested by man, the significance of prompt and adequate removal of sewage from possible contact with media and materials which may serve as vehicles of bacteria to man is apparent. There are several important hygienic aspects of this problem which will be discussed in the following order:

1. The production of disease by insects which may have been in contact with human excrement.
2. Bathing beach pollution by sewage.
3. Infection of public water supplies.
4. Infection of shellfish.

IMPORTANCE OF COMPLETE SEWERAGE SYSTEMS

Army camp management during the World War focused attention on precautions against the transmission of fecal bacteria by insects to man. The bitter experience of the Spanish-American War did not teach this lesson as thoroughly as it should have. A brief review of some of the evidence of the importance of excremental bacteria borne by insects to man is helpful.

Army Camps during the Spanish-American War.—The prevalence of typhoid fever among the American troops in camps during the Spanish-American War was unusually distressing. The morbidity or case rate from typhoid fever was 192.65 per thousand of mean strength. During this short period of less than 1 year practically one soldier in five suffered from this disease. The mortality from typhoid fever among the troops was 14.63 per thousand of mean strength.

The deaths from typhoid fever were 86.24 per cent of the total deaths among the troops in 1898. More than 90 per cent of the men who developed typhoid fever had no previous intestinal disease.

Lack of proper camp hygiene, with the result that disease germs were transmitted by flies from latrines to the food in the kitchens and in the mess tents, was the principal cause of the prevalence of typhoid fever, rather than the "embalmed beef" about which so much was written at the time.

Official typhoid fever statistics of the American army in 1898 are shown in Table 30.

Table 30.—Typhoid Fever Data, American Army, Spanish-American War, 1898

Camp	Number of regiments	Mean strength	Cases of typhoid fever		Deaths from typhoid fever	Deaths from all diseases
			Certain	Certain and probable		
Chickamauga....	22	27,380	2,912	5,921	344	397
Chickamauga....	17	20,568	1,741	4,418	417	469
Tampa.........	7	7,507	440	1,498	99	112
Alger...........	18	19,807	1,807	2,226	212	259
Meade..........	12	13,962	1,799	2,690	150	168
Jacksonville.....	9	10,759	1,729	2,693	248	281
Jacksonville.....	7	7,990	......	1,292	120	146
	92	107,973	10,428	20,738	1,580	1,832

Jacksonville.—This Florida city has for many years enjoyed a good public water supply obtained from deep wells. Typhoid fever was unusually prevalent during the warmer months of the year prior to 1911, when a systematic campaign was introduced for sewer extensions and for screening the remaining surface closets throughout those districts which had to await sewer extensions. Figure 2 shows the striking reduction in summer typhoid which followed the screening of the closets and the extensions of the sewers.

Policy as to Sewer Extensions.—Various authorities have cooperated recently to bring about a reduction in the transmission of disease through insects. This has led some to consider seriously whether extensions to sewerage systems were not for some cities a more important sanitary step to take than the installation of sewage treatment plants. This is not a subject to particularize upon, but it is believed that there are some cases

where extensions of sewers are the more important. Undoubtedly there are instances where both types of improvements are needed.

What has been said above applies to cities generally. It applies with more particular force to cities in warm than in cold climates, because the fly period is longer. Thus there are a number of southern cities which have a good public water supply,

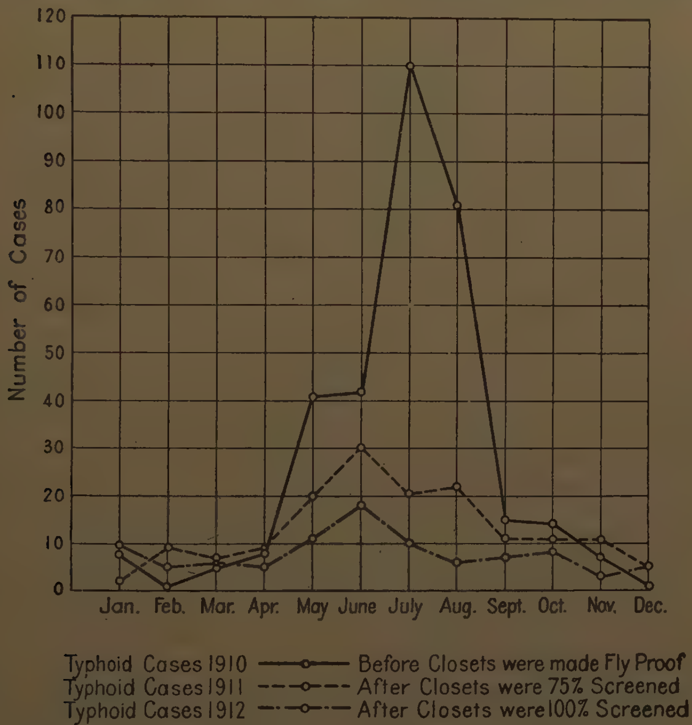


FIG. 2.—Seasonal distribution of typhoid fever, Jacksonville, Fla.

but which still fail to obtain, in spite of careful administration in many ways, as low a typhoid fever death rate as enjoyed by some other cities.

Hookworm Transmission and Soil Pollution.—The fore-going comments are directed more particularly to the short-comings of privies, cesspools and individual septic tanks, and the irregular and inadequate manner in which they are cleaned. Transmission of pollution and infection, from over-flowing arrangements in unsewered areas, by means of insects does not constitute the

only element of danger. Reference is made to soil pollution which constitutes a hazard for those who live in the midst of or who handle infected soil from such localities. Hook-worm is, perhaps, one of the most frequent and damaging of the diseases conveyed in this manner. Furthermore, such polluted material may be wind blown for surprising distances to make trouble where it is little suspected.

BATHING BEACH POLLUTION

Filthy conditions along the water front of oceans, estuaries, rivers and lakes, where bathing occurs, undoubtedly constitute one of the important reasons why American cities install sewage treatment plants, to maintain unimpaired the attractive shores of neighboring bodies of water.

This question, however, is by no means exclusively an esthetic one. Real danger lurks for bathers in waters to which sewage has access in substantial quantities, although the cited cases in support of epidemics are comparatively few.

At Vermilion, Ohio, the Ohio State Board of Health attributed an outbreak of typhoid fever to bathing in polluted water. Out of 36 replies received to a questionnaire sent out by this Board, 11 indicated transmission of disease through infected swimming pools. This view is by no means rare and undoubtedly exercised influence on the citizens at Cleveland in the determination to install sewage treatment plants, to improve the sanitary quality of the waters of Lake Erie at its municipal bathing beaches.

In 1924 and 1925, fairly definite epidemiological evidence incriminated some of the bathing beaches in the vicinity of New York City as causing a number of cases of intestinal disease.

INFECTION OF PUBLIC WATER SUPPLIES

It is hardly necessary to elaborate much upon this topic in a country where for the past 30 years steady progress has been made in the purification of polluted public water supplies. That there was necessity for water purification, because the supplies were sewage polluted, there can be do doubt, as may be noted from the typhoid fever statistics in Table 31.

In reviewing such data, however, it must be borne in mind that not only modern water filters, but chlorination of water supplies, pasteurization of milk, improved quarantine restric-

tions and anti-typhoid vaccination have played important parts in bringing about disease reduction.

Unfortunately all cities in this country cannot show a thoroughly satisfactory death rate from water-borne disease, and public water supplies of deficient character are still all too prevalent. In fact, Johnson estimated in 1916 that more than 3000 lives were lost each year in the cities of the United States by water-borne typhoid fever and that more than 45,000 cases of illness were due to this cause.

This situation involves in many instances the questions of treatment of both the sewage and the public water supplies. Within the scope of this book it is sufficient to describe, in this connection, a few well known cases to show the seriousness of sewage pollution of water supplies which are unfiltered and the care that must be exercised in preventing the sewage discharge of one community from damaging, beyond the possibility of reasonably complete correction, the public water supply of neighboring populations.

Lawrence Typhoid Record.—The city of Lawrence, Mass., derives its water supply from the Merrimac River about 8 miles below the outfalls of the sewers of Lowell, which discharge into the same river. Prior to 1893 Lawrence served its water consumers this polluted river supply without filtration. Typhoid fever prevailed to a high degree almost without interruption. For 7 years before the introduction of filters the annual typhoid fever deaths averaged 114 per hundred thousand population. During some years the rate was much higher than this. Following the introduction of water filters the death rate dropped at once to 25 or less.

Hamburg Cholera Epidemic.—In 1892 the River Elbe became infected with cholera germs said to have been conveyed in water ballast in boats from Havre, where cholera had been present for several weeks. The water supply for Hamburg was derived from this river and served to the citizens without filtration. A severe epidemic broke out and continued for several months. With a population of about 640,000, at that time, there appeared more than 17,000 cases of cholera and the total deaths from this disease amounted to half of this number.

The adjoining city of Altona also drew its water supply from the Elbe, from an intake about 7 miles below the Hamburg sewers. The number of deaths from cholera in Altona was about

TABLE 31.—ANNUAL TYPHOID FEVER DEATH RATES PER 100,000 POPULATION FOR SOME AMERICAN CITIES

Year	Philadelphia	Chicago	Milwaukee	Detroit	Cleveland	Buffalo	Boston	New York	Manhattan and Bronx	Jersey City	Baltimore	Washington	Pittsburgh	Cincinnati	Louisville	New Orleans	Minneapolis	St. Louis	Kansas City	San Francisco
1880	58	34	37	.....	44	....	42	25	....	24	59	54	135	70	....	24	....	40	....	34
1881	74	105	47	.....	99	67	56	38	....	63	58	46	151	71	....	30	....	53	....	37
1882	73	82	32	.....	68	69	57	32	....	121	47	66	158	55	....	33	....	45	....	61
1883	64	62	25	.....	65	34	52	32	....	49	35	62	107	51	....	23	....	41	....	64
1884	71	56	31	.....	60	42	56	29	....	84	42	76	70	56	....	25	....	42	....	58
1885	64	75	28	.....	34	23	40	27	....	71	42	65	76	42	....	17	....	31	....	44
1886	64	69	30	39	56	28	34	26	....	60	39	71	68	54	....	13	....	30	....	49
1887	63	50	31	65	52	34	44	26	....	54	41	78	128	142	....	15	....	28	....	23
1888	78	47	42	46	47	29	40	23	....	74	42	87	87	70	....	19	....	31	....	33
1889	71	48	28	31	74	30	43	24	....	83	47	94	95	49	....	17	....	33	....	55
1890	64	92	41	19	69	40	35	22	23	98	59	112	132	69	....	21	41	31	52	44
1891	64	174	33	34	50	51	34	23	25	100	35	82	101	62	....	24	55	29	42	42
1892	40	124	30	94	59	34	29	22	25	72	44	89	100	40	....	20	44	93	33	32
1893	41	54[4]	35	42	52	37	31	21	23	66	49	86	111	44	....	15	76	44	39	32
1894	33	38	25	28	29	59	29	17	19	53	47	91	56	55	....	29	56	34	26	37
1895	40	38	26	24	35	26	33	17	18	95	36	86	78	39	....	44	48	21	27	34
1896	34	53	18	23	43	20	31	16	16	84	38	58	62	52	....	33	32	20	23	26
1897	33	29	12	15	23	20	33	16	16	20	37	48	64	32	....	52	78	23	28	19
1898	46	41	17	22	34	27	34	21	20	40	36	71	73	33	....	66	44	17	37	41
1899	75	27	17	13	32	24	30	16	15	19	29	73	111	37	....	55	36	23	36	22
1900	35	20[3]	17	27	54	26	26	21	18	21	35	78	144	39	64	40	39	29	40	13

1901	34	29	22	21	36	27	25	20	19	16	27	60	125	55	46	48	59	34	44	22
1902	44[6]	45	15	24	33	33	24	21	18	20	42	78	134	62	61	45	27	37	36	27
1903	70	32	17	20	114	35	20	17	16	15	36	48	134	42	61	39	42	47	74	24
1904	53	20	14	20	48	23	23	17	13	19	37	47	142	79	63	36	42	36	39	27
1905	48	17	23	21	15[4]	23	20	16	13	19	36	48	99	40	51	32	25	20[5]	53	24
1906	74	19	31	24	20	23	20	15	15	20	35	50[1]	130	70	71	30	34	17	32	58
1907	61	18	26	35	19	28	10	17	16	14	41	35	125	45	71	55	27	15	33	30
1908	3[7]	16	17	22	13	20	25	12	11	9[10]	33	37	45	18[1]	47	33	19	14	29	19
1909	22[8]	13	23	23	13	23	14	12	12	9	25	33	23[1]	13	45	29[1]	21[5]	16	30	14
1910	17[2]	14	45	20	19	20	12	12	11[2]	7	42[2]	23	28[2]	6[2]	32[1]	32	....	13		
1911	14[9]	11	20	15	14	25[4]	9	11	10	8	27[10]	22	26	12	24	31	12	16	30[10]	15
1912	13[1]	7	26	15	7[2]	12	8	10	7	8	24	22	13	8	22	14	12	11	12	14
1913	16[10, 11]	10[2]	12[10]	25[10]	14	15	9	7[9]	7	11	22	16	20[10]	7	24	17	12[1]	17[10]	22	16
1914	8	7	8	11	8	16	9	7	6	8	21	11	15	7	27[10]	22	13	12	16	13
1915	7	5	5	10	8	10[10]	6	6	5	6	19	11	11	8	14	21	8	7[1]	10	[illegible]
1916	8	5	16	11	5	11	4	4	4	8	16[1]	12	9	3	14	23	6	10	12	3
1917	6	2[10]	6	13	7	10	3	4	4	4	13	12	12	4	16	24	7	8	12	5
1918	5	2	6	8	5[1]	7	3	4	4	5	10	11	10	5	15	20	9	8	15	4
1919	5	1	4	5	3	7	2	2	....	2	9	4[2]	4	3[10]	6	13	3	6	11	3
1920	3.4	1.1	2.2	5.1	3.3	5.1	1.5	2.4	2.1	3.7	4.7	6.6	2.7	2.7	5.5	7.0	2	2.7	7.4	3.1
1921	2.2	1.1	1.9	5.8	3.5	3.5	3.2	2.4	2.1	3.7	5.5	6.4	3.2	3.7	4.7	9.3	1.3	3.8	11.5	4.0
1922	2.8	1.1	2.5	5.3	2.2	3.6	1.4	2.2	1.9	1.6	3.9	5.1	3.3	3.0	7.2	5.7	1.8	4.4	4.6	4.3
1923	1.5	1.9	0.8	4.0[1]	1.9	4.1	1.3	2.4	2.5	1.6	4.1	6.0	2.1	3.0	4.1	4.0	1.5	4.2	4.8	2.6[2]
1924	2.2	1.6	1.0	3.0	1.2	2.8	2.1	3.1[10]	....	2.6	2.8	4.3	3.9	2.5	1.9	10.0	2.1	3.7	3.6	2.6
1925	2.3	1.5	1.4	2.7	1.5	4.5	3.5	3.3	....	4.1	3.6	5.0	3.2	4.2	5.8	19.8	3.3	3.9	1.9	2.2

1 Filtration effective for city.
2 Sterilization of water supply begun.
3 Drainage canal in service.
4 New intake.
5 Coagulation introduced.
6 One per cent of water supply filtered.
7 Fifty per cent of water supply filtered.
8 Ninety per cent of water supply filtered.
9 Sterilization of 66 per cent of water supply.
10 Sterilization of entire water supply.
11 Coagulant applied during periods of high turbidity.

one-sixth of that in Hamburg, for Altona water was carefully filtered. Most of the cases and deaths in Altona were traced to infections contracted in Hamburg.

Lowell Epidemic of Diarrhea.—The polluted Merrimac River water was accidentally pumped for a few hours into the water mains of Lowell, Mass. A fire had occurred at the Merrimac Mills which required the use of the city water as well as the corporation supply from the river. The two were connected by automatic gates which were supposed to prevent the polluted river water from entering the city pipes. One of these gates did not function, with the result that the city water was contaminated before the defect was discovered. This was on July 18–19, 1903. About July 23 numerous cases of diarrhea developed and on August 1 typhoid fever appeared. The reported typhoid cases were 161 in August, 39 in September, 17 in October and 14 in November, with 10 fatalities resulting.

The water pumped from the river was obtained only a short distance below one of the large sewer outlets. Although on July 30 the water pipes were flushed, a bacteriological examination made on July 29 and also on July 31 showed the presence of B. coli in the water from the city mains.

Auburn Typhoid Epidemic.—Pollution of the water supply of the city of Auburn in 1908 by sewage which entered the headwaters of Owasco Lake, 14 miles above the Auburn intake, was the chief feature of a typhoid epidemic which resulted in 12 fatalities and probably over 100 cases.

During the previous autumn some 20 cases of typhoid fever developed on the watershed of the lake. The largest number of them was at Moravia, a village of less than 2000 inhabitants and situated about 4 miles above the head of the lake on Mill Creek, a tributary of Owasco Lake. Practically all of the sewage contamination of the lake entered through this creek, on which was situated, besides Moravia, the village of Groton—less than 2000 inhabitants—and the village of Locke—with only a few hundred inhabitants. At Moravia was also the Union Free School having some 300 or 400 pupils and the sewage from this school also entered Mill Creek.

Subsequent investigations indicated clearly that it was possible for sewage to be transported the entire length of the lake which is 10 miles long, about a mile wide, and runs almost due north and south. It was shown that the time required for wind and water

currents to transport sewage from the head of the lake to the intake was only 2 to 3 days, or less than the period during which many typhoid bacteria in water remain alive and virile.[1]

SEWAGE BACTERIA AS RELATED TO SHELLFISH

Supposed oyster-borne epidemics during the past 25 years have been of sufficiently frequent occurrence to produce considerable agitation in the mind of the public. They have resulted in such a feeling of uncertainty that it has affected somewhat the shellfish industry, causing the dealers who handle shellfish from sources above suspicion to suffer from the faults of their competitors. In brief, the marketing in some places of shellfish from sewage polluted waters has produced a condition of affairs which needs correction in a practical way, both from the standpoint of the public health and of the shellfish industry.

While typhoid fever is the disease most discussed in this connection, it seems fair to say, reasoning from analogy, that cholera, diarrhea, gastro-enteritis and other diseases are entitled to consideration in studying exhaustively the effect of sewage bacteria upon shellfish.

New York, Chicago and Washington.—A consideration of the important problem of disease causation by polluted oysters is not complete without a reference to definite epidemic outbreaks of typhoid fever, during the period from November 16, 1924, to January 17, 1925, in Washington, D. C., Chicago, Ill., and New York City, and a markedly excessive prevalence, during the same period, in Buffalo, Cincinnati, Grand Rapids, Jersey City, Memphis, Pittsburgh, Providence, Rochester, Scranton and Yonkers. From such reports as are available, it is estimated that, within the epidemic period, there were over 1500 cases and 150 deaths from typhoid fever in excess of the normal expectancy for such period.

Most of these cases were carefully investigated by federal, state and municipal health and conservation officials. It is

[1] It is possible to expand indefinitely upon the examples of water-borne disease in the past 30 years. The typhoid epidemics cited have much in common with many that have occurred in more recent years. For further details as to earlier epidemics the reader is referred to "Sewage Disposal," by Fuller, McGraw-Hill Book Company, Inc., 1912, and as to more recent instances to various federal, state and municipal reports. Similar comment is noted with reference to oyster-borne epidemics.

generally accepted that the main factor in the spread of the infection, causing the excessive prevalence of typhoid fever, was raw shell oysters. There is considerable difference of opinion among the investigators as to the origin, actual or probable, of the oysters involved in the epidemic. There is little doubt, however, at least as far as circumstantial epidemiologic evidence is concerned, that the real source of the damage was the raw shell oyster.

Food Supply.—The oyster lives upon the various matters contained in sea water, about 90 per cent of the food being diatoms, or low forms of plant life, which are capable of growing largely on the mineral contents of sea water. This suspended matter, including that of sewage origin, if the water is polluted, reaches the stomach of the oyster, after having been filtered out from the water which passes through the gills.

Bloating and Bleaching of Oysters.—In all countries, one of the characteristic features of the oyster industry is the frequent, though not universal, custom of removing the oysters with rakes or dredges, after they have grown to be of a sufficient size, from the oyster beds proper, and their placement for a day or more in drinking houses, or floats. The latter are located ordinarily in coves or bays, or in the mouth of fresh-water streams, where the water is brackish. An object of this is to bloat, bleach or freshen the oysters. This is accomplished by the oysters drinking a comparatively large quantity of the brackish or fresh water. On account of difference in the specific gravity, they become bloated, with the salty flavor, due to sea water, largely removed. It also gives them a much lighter color, due to their being filled with fresh water.

Fattening of Oysters.—The above-mentioned bloating process, which the oystermen say increases the market value of the product, but which is seriously objected to by many devotees of fine oysters, is not to be confused with fattening, which, in a limited way, is done by transplanting to shallow bodies of salt water, where the diatomaceous food is more abundant than around the natural beds. The latter process is an important branch of artificial oyster culture, which has long received attention in France and elsewhere.

Opportunities for Pollution.—Enough has been said above to make it plain that the oyster, even in natural beds, may at times be found in a water which is dangerously polluted with sewage,

and that particularly dangerous pollution may be afforded by the custom of bloating the oysters by removing them to special layings along shore just prior to marketing. It is also apparent from what is said above that if disease germs are contained in the water in which the oysters are placed, there is a strong likelihood of these germs being filtered out by the oyster as the water passes through the gills and enters the body of the oyster.

LONGEVITY OF TYPHOID BACILLI IN WATER

For 35 years much study has been given by bacteriologists to the longevity of typhoid fever and other disease germs in water. Literature abounds with various references to their behavior. Some say they multiply rapidly and others say they die out very quickly. In natural waters, that is, those which have not been sterilized and treated in the laboratory, there is no doubt that ordinarily the typhoid germ not only does not multiply, but that it gradually dies. There may be some conditions in nature whereby typhoid fever bacilli might multiply in water, but if such is the case there are no well authenticated data in support of it.

The effect of temperature upon the life of the typhoid fever germs in water is clearly indicated in experiments described by the Massachusetts State Board of Health. It was found that, with water kept as near freezing as possible, a constant decrease in the number of germs occurred, but that some survived 24 days or more.

This conclusion is borne out by Whipple in his book on "Typhoid Fever," but it is also known that the length of life of the bacteria is quite variable as shown by laboratory tests. Freezing does not of itself cause sterilization, but alternate freezings and thawings are more destructive.

Generally speaking, it may be said that about 50 per cent of the bacteria will die in from 1 to 4 days and about 90 per cent of bacteria will die in from 3 to 13 days. A few of the most hardy cells continue to live for weeks and probably months, and constitute what Whipple calls the "resistant minority." Whether the germs of unusual resistance and longevity are more virulent or less virulent than normal is something about which practically nothing is known specifically.

Typhoid bacilli seem to die measurably more quickly in sewage than in fairly pure water. In all natural waters the amount of

organic matter present is such as to eliminate the quantity of food as a factor of importance. Their death in sewage is probably explained by the antagonism of other kinds of bacteria, or perhaps by the influence of enzymes or toxins produced by other kinds of bacteria. Another factor of importance is the absence of oxygen, which experiments indicate to be necessary for longevity, according to Whipple.

Investigations by Jordan, Russell and Zeit indicate that the typhoid bacillus is not so widely found in nature as early reports would indicate. In fact, where it occurs outside the human body it has been definitely traced only to places that would be likely to be infected by typhoid patients. While a few of the bacilli may live in fresh water for 2 or 3 weeks, may travel very considerable distances and retain their vitality for some days, it is also known, as stated above, that they do not multiply, but rather that they show a steady decline in numbers. Infection from fresh sewage is more to be feared than from stale sewage. However, typhoid germs do persist in soil for some time and human excrement used for manuring gardens involves more danger than many persons realize, particularly if related to raising vegetables which are eaten without cooking.

The important factor is the time element during which some of the typhoid germs will remain alive, in comparison with the period of transit to be expected in flowing streams and in estuaries where currents are set up by the action of winds and tides.

LIFE OF TYPHOID FEVER GERMS IN LIVE OYSTERS IN SEA WATER

Evidence upon this question has been obtained by several observers by putting oysters from unpolluted sources into small receptacles containing sea water infected with typhoid fever germs. From time to time examinations were made of the tissue, pallial cavity, alimentary tract, shell water, etc., of the oysters. All observers have found that these disease germs penetrate the oyster body and live there in gradually decreasing numbers for various periods, ranging from about 1 week to about 1 month.

RELAYING OF OYSTERS

For many years it has been the custom in France to relay oysters in disgorging tanks for a short time, with the view to causing the disappearance of disease germs before the oysters are placed on the market. This procedure was investigated in 1895

by Herdman and Boyce, and as the result of their observations they recommended that before the oysters were placed on the market they should be allowed to remain for a short time in water of well established purity. Merit in this proposition was testified to by a large number of competent observers in the hearings held by the Royal Commission on Sewage Disposal. As to the period of time required for polluted oysters to free themselves from all objectionable bacteria, the evidence is not conclusive. Most observers think that it would be safe make the period 2 weeks, while a few prefer a period of 3 or even 4 weeks. Taking everything into consideration, the Royal Commission, while recognizing the importance of the relaying of shellfish, not only from the point of view of public health, but also from that of the oyster trade, did not feel disposed to commit itself upon the practicability of the method, but strongly recommended further investigations of the matter.

SANITARY CONDITIONS OF LAYINGS OF OYSTERS AND OTHER SHELLFISH

During the past 20 years it is safe to say that most of the more important oyster beds, fattening grounds, etc., in this country and elsewhere have been examined with considerable care, either by official sanitary inspectors or by those who are competent to form a reliable general opinion as to their sanitary significance.

Similar attention has also been given to other shellfish, especially clams, the life history of which is more or less similar to that of the oyster.

Sanitary conditions can be definitely determined when the surroundings obviously show freedom from all pollution or when the sources in question are seriously and objectionably polluted. Unfortunately, many oyster layings come within the intermediate class, generally spoken of as "doubtful," about which it is difficult to arrive at a correct and reliable opinion as to the probable degree of pollution on some occasions. Concerning this doubtful class, information should cover reliably a wide range of conditions as to wind, weather and currents. In general all of the physical conditions should be considered, both subjectively and objectively, which relate to population as a possible polluting factor and the body of water or beds used for the cultivation of oysters or other shellfish.

ARTIFICIAL PURIFICATION OF OYSTERS

Wells, then of the United States Public Health Service, reported on this matter in 1916. He noted that 25 to 50 gallons of water per day pass through the oyster's gills and that in 5 hours after particles touched the gills they were ejected with the feces. Under favorable conditions a continuous stream of food material passes through the intestinal tract and is deposited in a solid ribbon beneath the oyster.

Observations by Phelps suggested that within a few hours oysters freed themselves in tidal currents during the summer months from B. coli when heavily inoculated with these bacteria. Within a few hours the greater part of the bacteria disappeared and even during the so-called "hibernating" period a few days in clear water were sufficient to wash out most of the sewage bacteria.

Experiments by Wells indicated the feasibility of purifying oysters coming from polluted water by placing them in a tank of water which was disinfected by a dose of commercial hypochlorite of lime. The dose was repeated after about 6 hours and apparently the result was satisfactory both with respect to the destruction of objectionable bacteria and the absence of interference with the normal activity of the oysters. This procedure, upon a working scale, is being used by an oyster producing company on Long Island. It is probable that the future will see a rapid increase in the procedure of artificial chlorination of oysters. Following the analogy of almost universal treatment of milk and water, regardless of source, it is not unreasonable to anticipate a more widespread usage of the Wells oyster chlorination process than has so far materialized. The requirement of safeguarding public health to the utmost may become the motivating factor. In the meantime large-scale or plant-size experimentation with the process is desirable in order to determine upon the usual costs and to iron out any mechanical difficulties that might appear.

CHAPTER IX

NATURAL PURIFICATION OF STREAMS

SYNOPSIS

1. Popular Conception.—Running streams have for decades been popularly understood by laymen to be capable of complete self-purification or natural purification, notwithstanding that this view has proved to be fallacious in the great majority of instances. In fact, it is the quiet streams which are the most readily purified owing to the opportunities for sedimentation and devitalization of objectionable bacteria. When floods come, however, such natural purification enounters a decidedly weak link in the chain of protection.

2. Time Factor.—Since typhoid fever germs will live in natural waters in diminishing numbers for a week or more, this time interval may far exceed the period required for some of the water to flow from points of pollution to points of use. In repeated instances a degree of natural purification has been assumed which was both unfortunate and erroneous.

3. Slow Oxidation.—Atmospheric oxygen with which mountain brooks are aerated as they flow over falls and riffles will do little or nothing towards oxidizing directly the polluting substances in sewage. In fact there is no measurable change in the organic content of the polluted Niagara River water after it has fallen over Niagara Falls.

4. Real Purification.—On the other hand, if sufficient time and reaeration are provided, bacterial and other natural agencies will bring about a substantial reduction of organic pollution as well as of objectionable bacteria. This has been strikingly shown in the lower Mississippi, where at New Orleans the water shows little effect of the pollution coming in the upper valley from some 10 millions population sewering into it. A factor of importance is that for several hundred miles above New Orleans, the river flows through the delta country where there is no pollution entering the stream.

GENERAL HISTORICAL FINDINGS ON NATURAL PURIFICATION

In the development of chemical and biological knowledge of self-purification of streams, investigators were not limited to physical observations as to what became of the visible sewage matters or to mathematical calculations of the degree to which the pollution in a given volume of water was lessened by the dispersion in a given volume of diluting water. They were in a position to measure the organic content of waters above and below points of pollution, by means of oxygen consumed and various nitrogenous products.

As long ago as 1870, a Royal Commission on River Pollution in Great Britain came to the conclusion that there was no river in England long enough to purify itself of pollution entering its upper reaches.

In the days before biologists and bacteriologists, and when the germ theory of disease and laboratory tests were unavailable, chemists were well aware of the dangers of drinking water polluted with sewage matters. In fact the filth theory of disease transmission served fairly well in England and elsewhere in protecting public health. Decomposition of organic matter and its relation to oxidation processes were quite well understood. It was known that the polluted water of the Niagara River showed only a very trifling change after passing over Niagara Falls. Atmospheric oxygen does not attack organic matter readily, as most laymen have believed, because it is in a molecular and not an atomic state like ozone. It combines with organic matter only when in an atomic condition. This means that there is comparatively little action between atmospheric oxygen and the organic matters of fresh sewage, because much, if not most, of such products are too stable for direct oxidation. Many hours elapse before bacterial decomposition exhausts the dissolved atmospheric oxygen, and such biological use of oxygen is the only way in which a substantial proportion of oxygen found in water polluted with sewage can be utilized.

In cases where polluted rivers are covered with sheet ice for long periods of time, the atmospheric oxygen naturally present in the water sometimes becomes exhausted. Bacterial decomposition processes then change from the aerobic to the anaerobic basis with attending bad tastes and smells in the water. This has occurred in river waters used as sources of public water supply, notably in the case of the Schuylkill River in Philadelphia during

the winter of 1882–3. Ice had cut off the oxygen supply, and foul smelling gases of decomposition made the city water supply objectionable for the consumers. In 1917 more or less similar experiences were encountered on the Maumee River above the intake of the Toledo water supply, due to organic wastes of sugar beet factories, the bacterial decomposition of which exhausted the dissolved oxygen in the river water.

FIG. 3.—Chicago canal system, Des Plaines and Illinois Rivers and vicinity, Lake Michigan to St. Louis.

Among the limited number of watercourses which have been investigated thoroughly for many years is the waterway beginning at the Chicago River and including the Chicago Drainage Canal, the Des Plaines River and Illinois River as it flows into the Mississippi 357 miles distant from Lake Michigan. The effects of dilution and of substantial self-purification were revealed

clearly by the results of numerous analyses made from January to June, 1900, representing the first 6 months of operation of the present drainage canal. It should be pointed out that the Illinois and Michigan Canal, the former channel through which the Chicago sewage was earlier discharged into the Illinois Valley, represented Chicago sewage with comparatively little dilution and is not to be confused with the present drainage canal beginning at Kedzie Avenue and paralleling the old Illinois-Michigan Canal to Lockport.

Notwithstanding the entrance of substantial sewage pollution at Peoria and other cities and towns along the Illinois River, it is noted that through natural agencies the purification of this watercourse is very substantial, both chemically and bacterially.

With the advent of bacteriology, self-purification was viewed in the light of the results obtained from this new and more effective means of measurement. Experiments of the bacteriologists brought a more rational understanding of what purification in watercourses through natural agencies really means. As Sedgwick pointed out, it is not running water that purifies itself so much as quiet water, in which the period of transit from point to point is far greater and in which sedimentation and the purification by various agencies are more completely effected. Of course, the scattering of sewage bacteria and other matters of a polluting nature due to the degree of dilution is not so influenced.

Before closing this description of some of the outstanding factors bearing upon self-purification as historically developed, it will be well to refer briefly to the facts ascertained by Weston at New Orleans in 1902 to the effect that almost no trace of sewage pollution, either as to organic matter or disease germs, could be found in the local muddy Mississippi River. This is quite remarkable in that about 10,000,000 people of the watershed above discharged sewage into this river and its tributaries. These observations show more decisively than any other information available that self-purification is a real phenomenon of large rivers. To appreciate the conditions of the lower Mississippi, it is well to recall that the mean and minimum stream flows are approximately 700,000 and 200,000 cubic feet per second, respectively. Furthermore, during the 500 or 600 miles by river above New Orleans the stream flows through what is known as the delta country. Most of the adjacent territory,

at flood stage, is below the water surface of the river which flows between levees and at that period the sewer systems of Vicksburg, Natchez and Baton Rouge were quite insignificant affairs. Thus it is seen that for quite a number of days this large Mississippi River above New Orleans flows between levees and receives comparatively no pollution, hence affording opportunity for the sewage bacteria of the upper valley gradually to perish. Furthermore, the organic matters become attached to the clay, silt and sand carried by this muddy river, and thereby they receive the purifying effects brought about by the soil bacteria and other agencies naturally present in this rapidly moving river.

SELF-PURIFICATION OF THE LOWER POTOMAC RIVER

In 1916 the United States Public Health Service published in Bulletin 104 the results of long continued observations on the sanitary condition of the water and shellfish in the lower Potomac River, with special reference to self-purification. These investigations showed that, in the stretch of river below Washington, but not in the unpolluted part of the river above, nor in the lower tidal estuary, there were characteristic organisms both in the river water and in the bottom mud. Organisms characteristic of sewage pollution were substantial factors in bringing about self-purification of the Potomac River with the result that at a location about 50 miles below Washington, the water was as good as above the city. Furthermore these organisms disappeared proportionately to the time and distance intervening down the river from the point of sewage pollution.

These microscopic organisms are larger than the bacteria and play an important part as scavengers. In turn some forms which are found in polluted, but not in clean, water serve as food for other kinds, including fish life. Thus there is brought into the field of natural purification of rivers an agency which has been carefully studied in several localities but which is only meagerly appreciated in the consideration of this broad subject, as will be outlined in Chapter XI.

BIOLOGY OF THE UPPER ILLINOIS RIVER

The Natural History Survey of the State of Illinois has contributed notable study of much practicable merit for the Upper Illinois River from the Chicago Drainage Canal through the Des Plaines and Illinois River systems. The work included the

studies of Kofoid from 1894–9 and various later investigations conducted by Forbes and Richardson. These investigations and those of the United States Public Health Service in 1921–2 will be detailed in Chapter XI, but here it may be stated that plankton was found to be a substantial element in natural purification along the lines just noted in the Potomac River investigations. Furthermore, certain algae or chlorophyll containing organisms were substantial producers of oxygen which aided the purification process.

NATURAL PURIFICATION OF THE OHIO RIVER

Surveys and laboratory studies by the United States Public Health Service on the Ohio River constitute a notable work. The results are set forth in Public Health Bulletins Numbers 131, 143 and 146 of the United States Public Health Service. The data obtained deal with plankton, bacterial pollution, the deoxygenation of the water and the influence of reaeration under conditions found. The latter phenomenon provides additional atmospheric

TABLE 32.—BACTERIA REMAINING BELOW THE SEWER OUTFALLS OF THE CINCINNATI METROPOLITAN DISTRICT

Mean gage height, feet	Mean time from sewer outlets, hours	Reduced to basis of 100 per cent* at maximum		
		Agar	Gelatin	B. coli
24.9	3.2	93.52	91.79	82.36
21.2	7.2	79.04	80.32	84.50
10.6	11.9	96.95	99.87	100.00
12.1	17.4	100.00	100.00	91.83
11.4	25.2	66.65	81.08	67.45
16.1	35.3	49.05	77.41	36.83
9.8	44.8	29.96	54.35	37.67
9.7	60.5	18.82	29.95	16.41
9.8	83.4	9.43	13.66	10.99
7.0	112.6	3.71	4.82	5.42
6.1	139.9	1.14	1.59	1.23
4.3	182.9	0.68	1.12	0.380
4.4	219.2	0.58	0.95	0.122
3.4	258.2	0.21	0.38	0.174
2.5	314.8	0.070	0.104	0.175
1.3	497.7	0.063	0.100	0.065

* Figures noted in these columns are in per cent of the numbers observed in the zone of maximum pollution below that district, April to November, inclusive, 1914, 1915, 1916.

oxygen to bring about bacterial decomposition without objectionable and offensive results. These investigations will be touched upon in later chapters, but it is desired here to point out the progressive decrease in bacterial population coming from the sewers of the Cincinnati district at sampling stations in the Ohio River below. The tested samples correspond to stated intervals of time for passage of the water from the sewer outlets above, at different river stages. The average results found are shown in Table 32.

NATURAL AGENCIES OF STEAM PURIFICATION

Before proceeding to discuss in further detail in following chapters the conditions of oxygen demand by bacterial growths, the effect of reaeration in promoting the decomposition of organic matter in streams on an aerobic basis and the effect of plankton or microscopic growths of organisms larger than bacteria, a summary of the principal factors accompanying stream purification is desirable.

Dispersion.—Dilution or dispersion of 1 volume of sewage in 50 volumes or 100 volumes of water obviously means an improvement to the sewage as it leaves the sewer outlet. If it is mixed with about 100 times its own volume, the resulting mixture will contain only about 1 per cent of pollution, comparatively speaking. As some state it, this means about 99 per cent purification on the assumption that the entering sewage is thoroughly mixed or dispersed throughout the diluting water.

Sedimentation.—Except at times of floods or in rapidly flowing streams sedimentation is likely to be a factor in the case of many streams. Where it does occur, the flowing river below the banks of sewage mud is appreciably better than would otherwise be the case. When the flood come, however, and the accumulated deposits of sewage mud are flushed out, it is quite possible that the stream below, as a result of containing such accumulations for weeks and months, may be far more polluted than would be the case in dry weather in the absence of any sedimentation. Velocities in rivers are found from almost nothing up to currents of 3 to 6 miles per hour, and even more in turbulent streams above falls and rapids.

Scouring Velocities.—In the case of sewers receiving no street wash, a velocity once or twice a week of 28 inches per second

will dislodge stranded sewage solids. The longer the time interval between flood flows, the higher will be the required velocity in order to dislodge deposits which become compacted with time and also as a result of decomposition of organic matter, in which hydrogen sulphide is produced and it combines promptly with salts of iron so as to form a gelatinous precipitate of ferrous sulphide. In all small streams where there are mill ponds some deposits are no doubt permanent.

Longevity of Disease Germs.—Typhoid fever bacilli and similar enteric organisms, most frequently considered in studying the question of self-purification of streams from the standpoint of infection of river water at intakes, will not multiply under any ordinary conditions after they are discharged into river waters. They will live for quite a number of days in gradually diminishing numbers, with the resistant minority living for a longer period in relatively clean water than in highly polluted streams.

Typhoid fever bacilli may be assumed to have a life in transit in ordinary water from sewer outlet to waterworks intake when measured by time intervals substantially as follows:

About 50 per cent will die in from 1 to 4 days, and about 90 per cent in from 3 to 13 days.

Jordan states that the typhoid bacillus can survive in sterile water, in glass vessels for upwards of 3 months and possibly for 2 or 3 weeks in unsterilized ground or surface water. Other evidence indicates that this bacillus is able to travel in water a distance of at least 140 kilometers or about 90 miles and to retain its vitality in bodies of water for at least 4 or 5 days.

Oxidation.—Soluble organic matters in sewage, after entering a stream, will not be directly oxidized to a great extent by the atmospheric oxygen dissolved in the water of the stream. Bacterial decomposition, however, in the presence of oxygen will gradually bring about the conversion of complex organic matters into simple harmless products. It is promoted by reaeration as the water is exposed to the atmosphere and also by the oxygen produced by certain forms of microscopic growths. These and other factors are discussed in Chapter X on "Oxygen Balance."

Plankton.—Various forms of animal and vegetable life larger than the bacteria are a specific help in many places in bringing about the elimination of matters of sewage origin. Chlorophyll plants produce oxygen for bacterial decomposition in an inoffensive way, as will be pointed out in Chapter XI on "Plankton."

CHAPTER X

OXYGEN BALANCE: RESIDUAL OXYGEN

SYNOPSIS

1. Need of Oxygen.—In streams and some purification processes, it is necessary to provide sufficient oxygen for aerobic bacterial action so as to avoid putrefaction.

2. Oxygen Balance.—The term "oxygen balance" designates the relation between the oxygen demanded by the organic matter of the entering sewage and the available oxygen found in the water serving as a diluent. When the oxygen demand of the organic matter does not exceed the available oxygen of the receiving body of water, it may be said that the "oxygen balance" is positive, and nuisance ordinarily will not result. When the relationship is reversed, the "oxygen balance" is reversed, and in consequence of negative balance, nuisance results.

3. Needed Dilution.—Repeated observations show that, when there is dilution of from 4 to 7 cubic feet per thousand population connected with the sewer system discharging into a watercourse, there will ordinarily be no offense. This is a rough yardstick and is subject to the exceptions already discussed in Chapter VII.

4. Oxygen Demand.—The average total oxygen demand of sewage per capita in cities with separate systems of sewers is about 0.17 pound or 77 grams per capita daily, according to the Committee on Sewage Disposal of the Chicago Board of Review. This same Board placed the corresponding figure for the sewage from combined systems of sewers at 0.24 pound or 109 grams per capita daily.

5. Dissolved Oxygen.—The oxygen dissolved in the water of a given watercourse depends upon temperature and the extent to which the oxygen has been depleted below the saturation point by aerobic bacterial activities occurring before the water is used as a diluent. It ranges, when the water is saturated, from 14.62 parts per million at 32° F. to 7.63 parts at 86° F. In relatively clean waters the actual available oxygen is frequently not more than 80 to 90 per cent of that required for saturation at a given temperature. Hence careful investigations are necessary to

determine the effect of seasonal variations in the main body of the diluting water as well as in tributaries thereto.

6. Residual Oxygen.—So long as water contains some dissolved oxygen throughout its entire volume, the water is not actively in a putrefactive state. Putrefaction does not set in until available oxygen is exhausted, and so long as there is residual oxygen, nuisances will not result, although it is necessary to consider carefully associated conditions related to both positive and negative items which affect the oxygen balance.

7. Associated Factors.—Available oxygen is increased in bodies of water receiving sewage in consequence of the oxygen produced by micro-organisms living in the water and particularly by that which comes from reaeration. On the other hand, the oxygen supply is depleted by pollution coming from elsewhere than the locality under review. In particular it is necessary to consider the oxygen demand of accumulated sludge deposits. The latter produce gaseous substances to a greater extent with the warm temperatures of summer than in the winter and hence at a time when the greatest stress comes on the oxygen balance. It unfortunately happens that water over-lying sludge deposits is depleted by gases released from sludge which may have been deposited on the bed of the watercourse some months previously.

8. Margin against Nuisance.—While residual oxygen sufficient to record a positive quantity in all places will suffice to avoid nuisance, it is necessary to consider factors of safety to provide for unexpected conditions. Suggested residual quantities of 50 to 75 per cent of the oxygen necessary for saturation are by no means necessary, although decomposing sludge deposits, even with such quantities of oxygen present in the over-lying water, may cause offensive smells at times, until the sludge banks are decomposed and additional accumulations are prevented by sludge removal plants.

9. Fish Requirements.—Residual oxygen is a factor related to the requirements of major fish life which varies with the type of fish and other factors. This limit may be stated to approximate 1.5 cubic centimeters per liter or about 2.5 parts per million, according to leading observers.

RECENT DEVELOPMENTS

Oxidation subjects have received careful investigation, particularly through the researches of the Sanitary District of

Chicago and of the United States Public Health Service, which has studied this phase of the natural purification of the Ohio River, as well as of the Chicago Drainage Canal and of the Des Plaines and Illinois Rivers. Much light was shed on this subject by the reports of the Royal Commission on Sewage Disposal, with its conclusion that stable effluents should show a biochemical oxygen demand of not over 20 parts per million in 5 days at 65° F.

Theoretical aspects of this problem have been well set forth in United States Public Health Service Bulletins, Numbers 143 and 146, and in papers before the American Society of Civil Engineers, April 1925, by H. W. Streeter and E. J. Theriault. In these papers reference is made to important work by Black and Phelps, Adeney and other earlier workers.

An outstanding summary of all of these investigations and methods as applied to the Chicago problem is to be found as Appendix 1 of Part III of the report of the Engineering Board of Review of the Sanitary District of Chicago. This report, dated February 21, 1925, was prepared by the Committee of the Board on Sewage Disposal, consisting of Messrs. Eddy, Fuertes, Gregory, Hatton, Hubbell, Marston and Phillips.

OXIDATION TERMS AND FACTORS

Quantitative considerations of the extent of stream pollution involve appreciation of a number of factors which may conveniently be defined as follows:

Oxygen Demand.—This is the amount of atmospheric oxygen required for the oxidation of organic matter to proceed to the point where bacteria on an aerobic basis are able to effect no further decomposition.

Available Oxygen.—This is the amount of atmospheric oxygen dissolved in the particular sample of stream water. Theoretically some oxygen may be made available from nitrites or nitrates before putrefaction or anaerobic decomposition sets in. But ordinarily this source of oxygen is left out of the account and assumed to be a factor of safety.

Oxygen Balance.—A positive oxygen balance occurs when the available dissolved oxygen present exceeds the oxygen demand. On the other hand, if the oxygen demand exceeds the available oxygen, then there is a negative oxygen balance and the water will putrefy, if reaeration does not supply the deficit. So long as the particular sample contains dissolved oxygen throughout its

entire volume, then the water is not actively in a putrefactive state. As time is required for the bacterial decomposition of organic matter, a sample of water actually containing dissolved oxygen may later putrefy, unless the oxygen available, together with reaeration, is adequate when measured against the oxygen demand.

Oxygen Demand Tests.—This question is dealt with in Standard Methods of Water Analysis published by the American Public Health Association and by the American Water Works Association in 1925. A sample is incubated at a definite temperature, usually 20° C., for a certain period, generally 5 days or 10 days. The difference in dissolved oxygen before and after incubation is the oxygen demand. Recent investigations have been based on the requirements for 5 days at 20° C., which is assumed to represent 68 per cent of the 20-day oxygen demand. Large particles of suspended matter may disturb this relationship somewhat. In a general way the 5-day oxygen demand may be taken at about 68 per cent of the 20-day and the 10-day oxygen demand at about 90 per cent of the 20-day.

Deoxygenation.—This term is applied to the utilization of dissolved oxygen in the decomposition of organic matter through bacterial activities on an aerobic basis. Phelps indicates a law for this step: "The rate of biochemical oxidation of organic matter is proportional to the remaining concentration of unoxidized substance, measured in terms of oxidizability." Time and temperature are important factors in deoxygenation, but in nature it is necessary to consider the freshness of the organic matter and the relative proportion of remaining organic matter subject to biochemical decomposition. This general process is spoken of either as deoxygenation of the stream water or as the biochemical decomposition of the organic matter therein.

Reoxygenation.—Having dealt with the relation of oxygen demand of sewage to the deoxygenation of the stream water, it is important to consider replenishment of oxygen in a stream from three natural sources:

(*a*) Dilution water entering the stream through the medium of tributaries and local inflow,

(*b*) Biological reoxygenation through the activities of certain oxygen producing plants, and

(*c*) Atmospheric reaeration, or absorption of oxygen direct from the atmosphere.

Reaeration particularly for long watercourses is an important source of oxygen for maintaining a positive oxygen balance.

Residual Oxygen.—This expression is applied to the dissolved oxygen content of the stream water at a given location after deoxygenation has had time to occur. It is of particular significance in reference to the requirements of major fish life and the prevention of nuisance.

We set forth in some detail the items particularly considered under this general subject as investigated under conditions found in the Illinois and Ohio Rivers. They typify the problems of large waterways, but on account of their length and other factors those problems are more complicated than ordinarily found for smaller streams. At the end of the chapter comment is made as to practical use of data here given.

OXYGEN DEMAND

The Chicago Committee, in collaboration with the sanitary engineers and chemists of the United States Public Health Service, reviewed available data in 1925 and summarized 20-day oxygen demands[1] of sewage in Table 20, Chapter IV. For separate and combined sewer systems their estimates averaged 0.17 and 0.24 pound per capita daily, respectively.

The "population equivalent" of the wastes from the stockyards and other industrial plants in Chicago is computed from results of the biochemical oxygen demand and then converted into the number of population producing sewage with an organic content bearing an equal demand for biological oxygen. The figures were developed from Table 33.

[1] It is important to point out that the demand for oxygen proceeds in two stages. The 20-day demand may or may not be 99 per cent of the ultimate requirement, but, for practical purposes, the 20-day figure gives a sufficiently safe criterion of oxygen requirements to be entirely useful. The theoretical aspects of the problem are thoroughly discussed by Theriault in references cited in this chapter.

Table 33.—Oxygen Demands of Wastes from Industrial Plants in Chicago, 1917

Firm	Flow, (c.f.s.)	10-day oxygen demand, (pounds per 24 hours)
Swift & Co	14.21	74,050
Armour & Co	14.39	48,370
Union Stockyards Company	4.01	2,460*
Morris & Co	5.93	36,000
Wilson & Co	4.06	22,130
Hammond & Co	1.53	9,070
Libby, McNeil & Libby	1.07	6,640
Independent Packing Co	0.43	3,320
John Agar Company	0.34	3,880
Western Packing Company	0.26	1,290
Guggenheim Brothers	0.22	5,800
Boyd-Lunham Company	0.22	2,170
Darling & Co	0.37	6,520
Brennan Packing Company	0.20	1,630
Peerless Packing Company	0.17	2,510
Oppenheimer Casing Company	0.16	2,770
Chicago Packing Company	0.22	2,700
Anglo-American Provision Co	0.13	1,010
L. Pfaelzer & Sons	0.13	810
Bechstein & Co	0.11	1,800
Miller & Hart	0.11	1,550
American Gut String Co	0.10	130
Siegel-Hechinger	0.09	1,530
North American Provision Co	0.07	850
Roberts & Oake	0.06	1,200
Friedman Manufacturing Co	0.06	580
Northwestern Glue Company	0.05	840
D. Levi	0.04	420
J. J. Cullinan	0.03	450
J. R. Beiersdorf & Brother	0.01	50
B. Pfaelzer	0.01	40
Total	66.64	242,570

Population equivalent = 242,570 ÷ 0.22† = ... 1,100,000
Rounded off to 1,000,000

* Estimated.

† 10-day oxygen demand factor, pounds per capita per day.

TOTAL OXYGEN DEMAND LOADS

Knowing the population at present attached to a sewer system discharging into a given watercourse, or after having made estimates of future population, it is a relatively simple matter to estimate the total amount of oxygen demand for a city at a stated date. It involves the use of the pounds per capita of oxygen required, with a corresponding item for industrial wastes. Thus the oxygen demand loads at Chicago at stated dates were estimated by the Chicago committee as in Table 34.

TABLE 34.—OXYGEN DEMAND LOADS OF CHICAGO SEWAGE AND INDUSTRIAL WASTES IN 1920, 1930, 1945 AND 1955

Year	Population			Total oxygen demand, (pounds per day)		
	Human	Industrial equivalent	Total	Human	Industrial equivalent	Total
1920	3,000,000	1,500,000	4,500,000	720,000	360,000	1,080,000
1930	3,710,000	1,700,000	5,410,000	890,000	410,000	1,300,000
1945	4,785,000	2,000,000	6,785,000	1,150,000	480,000	1,630,000
1955	5,500,000	2,200,000	7,700,000	1,320,000	530,000	1,850,000

AVAILABLE DISSOLVED OXYGEN

Lake Michigan water used for diversion and dilution of sewage from the Sanitary District of Chicago contains dissolved oxygen as presented in Table 35.

TABLE 35.—MONTHLY AVERAGES OF DISSOLVED OXYGEN* IN LAKE MICHIGAN WATER

	September, 1921, through August, 1922			September, 1922, through August, 1923		
	Temperature ° C.	Dissolved oxygen, (p.p.m.)	Per cent saturation	Temperature, ° C.	Dissolved oxygen, (p.p.m.)	Per cent saturation
Sept.	18.7	9.73	105.3	19.6	8.43	91.2
Oct.	13.7	9.62	92.1	14.6	9.47	92.4
Nov.	8.0	11.25	94.8	9.3	10.69	92.6
Dec.	4.4	11.65	89.6	4.3	12.97	99.5
Jan.	3.0	13.03	97.4	2.0	13.93	100.7
Feb.	2.8	12.37	91.3	2.2	13.98	101.5
March	4.7	12.88	98.9	2.8	13.08	96.5
April	9.6	11.37	99.4	7.6	12.08	100.8
May	13.5	11.03	105.4	11.4	10.15	92.2
June	19.0	9.36	100.1	15.8	9.21	92.6
July	21.7	8.45	93.4	18.6	7.76	83.9
Aug.	22.3	7.88	89.7	20.8	7.72	85.5
Average	11.8	10.72	96.5	10.8	10.79	94.1

* Determinations made daily at 39th Street Pumping Station by Sanitary District of Chicago.

SEASONAL VARIATIONS

The above table shows that there is far less oxygen in the lake water in summer than in winter. In a large measure this is due to the change in coefficient of absorption with temperature,

TABLE 36.—SOLUBILITY OF OXYGEN IN FRESH WATER*

Temperature in degrees		Dissolved oxygen, (p.p.m.)
Centigrade	Fahrenheit	
0	32.0	14.62
1	33.8	14.23
2	35.6	13.84
3	37.4	13.48
4	39.2	13.13
5	41.0	12.80
6	42.8	12.48
7	44.6	12.17
8	46.4	11.87
9	48.2	11.59
10	50.0	11.33
11	51.8	11.08
12	53.6	10.83
13	55.4	10.60
14	57.2	10.37
15	59.0	10.15
16	60.8	9.95
17	62.6	9.74
18	64.4	9.54
19	66.2	9.35
20	68.0	9.17
21	69.8	8.99
22	71.6	8.83
23	73.4	8.68
24	75.2	8.53
25	77.0	8.38
26	78.8	8.22
27	80.6	8.07
28	82.4	7.92
29	84.2	7.77
30	86.0	7.63

* From Standard Methods for the Examination of Water and Sewage.

although in part it is due to depletions in oxygen due to local conditions and bacterial decomposition. The main difference in seasonal content of dissolved oxygen is due to differences in solubility as set forth in Table 36.

AVAILABLE OXYGEN FROM TRIBUTARY STREAMS

The Chicago report shows available dissolved oxygen in the waters of present tributary streams to the Illinois River above Chillicothe. These data illustrate well the marked variations to

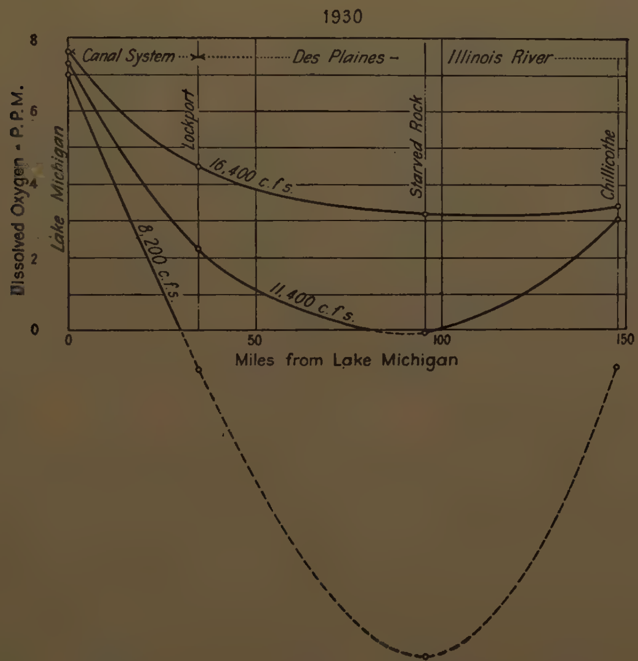


FIG. 4.—Estimated dissolved oxygen in Chicago canal system and Des Plaines-Illinois River for 1930 summer conditions, with different flows at Lockport.

be found in the net dissolved oxygen in different streams. This expression is taken as the margin between the oxygen demand and the dissolved oxygen actually found in the waters. During summer it should be noted in Table 37 that the net dissolved oxygen showed in some cases a negative result. That is, the organic matter, if decomposed completely, as would be the case if the bacteria were afforded sufficient time to change it to inert

TABLE 37.—AVAILABLE DISSOLVED OXYGEN IN WATERS OF PRINCIPAL TRIBUTARY STREAMS ABOVE CHILLICOTHE (September, 1921, to August, 1922, Monthly Averages)

Month	Des Plaines River at Lemont			Kankakee River at mouth			Fox River at mouth			Vermilion River at mouth		
	Net dissolved oxygen, (p.p.m.)	Average discharge, (c.f.s.)	Net dissolved oxygen, (pounds per day)	Net dissolved oxygen, (p.p.m.)	Average discharge, (c.f.s.)	Net dissolved oxygen, (pounds per day)	Net dissolved oxygen, (p.p.m.)	Average discharge, (c.f.s.)	Net dissolved oxygen, (pounds per day)	Net dissolved oxygen, (p.p.m.)	Average discharge, (c.f.s.)	Net dissolved oxygen, (pounds per day)
1921												
Sept.	2.48	44	589	4.98	1,230	33,100	4.42	807	19,300	3.67	290	5,750
Oct.	2.00	198	2,140	6.67	1,120	40,400	6.44	1,659	57,700	6.52	187	6,580
Nov.	5.55	896	26,850	7.66	4,844	200,500	7.10	2,166	83,000	6.89	1,020	38,000
Dec.	6.59	1,609	57,300	8.72	5,805	273,000	7.89	3,584	152,700	8.58	1,270	58,800
1922												
Jan.	3.83	493	10,200	9.31	4,861	244,000	8.06	2,260	98,200	8.82	443	21,100
Feb.	0.02	121	13	6.49	3,871	135,600	6.55	1,148	40,600	7.21	708	27,600
Mar.	3.13	1,034	17,500	6.99	9,199	347,000	2.95	3,236	51,500	8.11	2,560	112,000
Apr.	5.54	1,598	47,800	5.18	19,610	549,000	5.14	4,556	126,500	7.10	4,520	173,000
May	0.11	251	149	5.56	5,160	154,800	4.96	1,481	39,600	6.62	775	27,700
June	−3.36	66	−1,197	5.62	1,923	58,300	5.61	621	18,800	4.50	188	4,570
July	−4.38	40	−946	5.63	1,022	31,100	5.39	531	15,500	3.59	88	1,700
Aug.	−3.59	33	−640	5.17	713	19,900	4.04	327	7,150	1.88	1	10

matter, would demand more oxygen than would be available. A map of the waterways dealt with in the Chicago report is shown in Fig. 3. Estimates of dissolved oxygen at different points with different flows are charted in Fig. 4.

OXYGEN FROM MICRO-ORGANISMS

Chlorophyll bearing organisms produce oxygen in river stretches of relatively clear water when the sun shines and when suitable food is present. They live upon carbon dioxide and nitrates. In heavily polluted river water their growth is much restricted. In the Illinois River where the water is moderately clear and free of excess pollution, they frequently produce substantial quantities of oxygen, many tests indicating super-saturation. But no data are available to indicate the quantity of oxygen which they produce in polluted turbid streams. The influence of sunlight on oxygen production, known technically as photosynthesis, is shown in the diurnal variations in oxygen coming from micro-organisms. While this is a factor under some conditions, it may be generally stated that it is not an item of great significance under conditions where close figuring is necessary in order to maintain the oxygen balance.

REAERATION[1]

This is an important source of dissolved oxygen. As the latter is depleted, oxygen is absorbed from the air in quantities varying directly with the deficiency which the water in question shows as to dissolved oxygen content. Naturally the rate of absorption increases with the agitation or turbulence of the water. The United States Public Health Service investigations during the summer of 1922 led to estimates in the Chicago Report of increases above zero dissolved oxygen as shown in Table 38.

TABLE 38.—OXYGEN ABSORBED FROM AIR
(Pounds of Oxygen per Day per Thousand Square Feet of Water Surface)

Canal system above Lockport	2
Lockport to Brandon's Bridge	16
Brandon's Bridge to Starved Rock	4
Starved Rock to Chillicothe	2

The above figures are given for illustrative purposes and should not be taken too seriously as a criterion for reaeration

[1] For more complete discussion, see Streeter, U. S. Public Health Service, Public Health Bulletin No. 146.

under other and more normal circumstances, where the dissolved oxygen is well above the zero point assumed in the above estimates. Naturally the depth of water is a factor influencing the

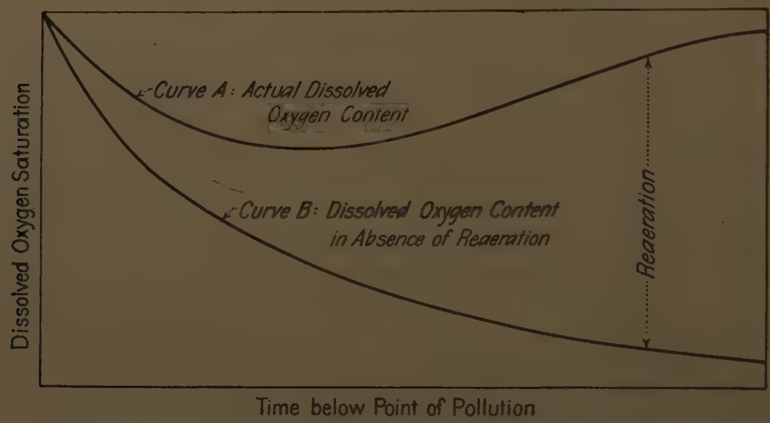


FIG. 5.—Effect of reaeration on progressive changes in dissolved oxygen below an assumed point of pollution.

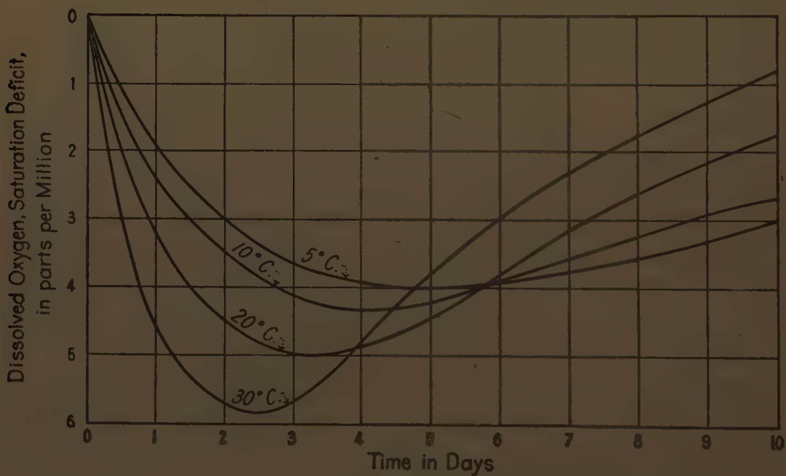


FIG. 6.—Effect of temperature variations on progressive changes in dissolved oxygen content.

extent to which aeration of the surface influences the dissolved oxygen content of the entire body. The above estimates are also based on the assumptions that the rates of reaeration per unit of water surface for the different stages with different flows

are directly proportional to the velocities and inversely proportional to the time of flow.

Reference is made to the researches cited at the beginning of this chapter, for those who desire to study in detail the theoretical considerations involved. Without doubt reaeration is an important element for replenishing dissolved oxygen in many bodies of water, as is well exhibited by the fact that adequate

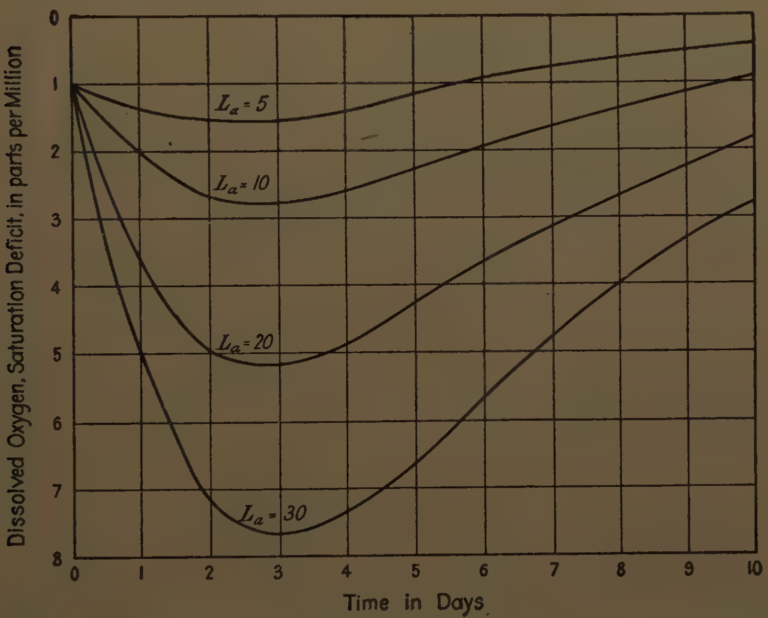


FIG. 7.—Effect of variations in initial oxygen demand La on progressive changes in dissolved oxygen.

aeration is afforded at several important activated sludge plants as a result of mechanical appliances producing wave action or disturbance of the surface of the moving sewage in shallow tanks.

The significance of these matters will be better appreciated by noting Figs. 5, 6 and 7.

OXYGEN DEMAND OF SLUDGE DEPOSITS

It is well known that in bodies of water where banks of sewage sludge or mud accumulate, the dissolved oxygen content of the over-lying water is more or less depleted by products arising from the putrefaction of sludge deposits. This is much more notice-

able in the summer when warmer temperatures promote putrefaction, not only of the freshly deposited sludge, but also of the accumulations of many months during the intervals since biological agencies were stimulated by the favorable temperatures of the preceding summer.

The Sewage Disposal Committee of the Chicago Board of Review made inquiry into this matter as revealed by the data accumulated by the United States Health Service and the staff of the Sanitary District. They made a comparative study of the oxygen balance for different stages of the canal and river system

TABLE 39.—ESTIMATES OF TOTAL OXYGEN DEMAND EXERTED BY SLUDGE DEPOSITS IN DIFFERENT STRETCHES OF CANAL SYSTEM AND DES PLAINES-ILLINOIS RIVER*

(July and August, 1922)

	Canal system to Lockport		Brandon's bridge to Ottawa		LaSalle to Chillicothe	
	July	August	July	August	July	August
Area of water surface, (thousand square feet)	48,600		156,800		205,930	
Estimated rate of reaeration at zero dissolved oxygen, (pounds oxygen per thousand square feet per day)...	2		4		2	
Gross re-aeration, (pounds oxygen per day)†.....	80,000	80,000	627,200	627,200	411,860	411,860
Net change in oxygen balance, (pounds per day)................	−274,600	−257,600	−121,540	−7,890	+231,380	+127,440
Total oxygen demand exerted by sludge, (pounds per day)......	354,600	337,600	748,740	635,090	180,480	284,420
Average total oxygen demand exerted by sludge, (pounds per day).....	346,100		691,910		232,450	
Average oxygen demand exerted by sludge, (pounds per day per capita)‡.............	0.077		0.154		0.051	
Total oxygen demand exerted by sludge, including stretch above, (pounds per day per capita)..............	0.077		0.231		0.282	

* Without correction for effect of sedimentation of solids.

† Dissolved oxygen above Lockport assumed to average 1.5 p.p.m. and below Lockport to be completely exhausted.

‡ Based on estimated contributing population of 4,450,000, including industrial wastes equivalent population.

and in particular studied the deterioration in oxygen balance due to total oxygen demand. They estimated the difference due to sludge deposits after taking into account the effect of sedimentation of sewage originally present in the moving stream.

The Committee estimated that in the lower stages of the Illinois River the total cumulative effect of sludge on total oxygen demand amounted to 0.282 pound per capita per day. A summary of their estimate is given in Table 39.

EFFECT OF SHEET ICE

During severe winter weather when streams are completely covered by sheet ice, the regimen of the oxygen balance is disturbed. This comes chiefly from the elimination of reaeration and partly from the confinement within the flowing water of products of decomposition particularly on an anaerobic basis. Local conditions vary so that it is futile to attempt to draw generalizations. It is of interest, however, to note that the Chicago committee found instances of a month's duration or so when a normal diluting flow of 8000 cubic feet per second should have been increased about 50 per cent or to 12,000 cubic feet per second.

REGULATED DILUTION

The 1925 Chicago reports on the Chicago Drainage Canal and diversion of Lake Michigan water through it accentuated the fact of there being required during the winter months a much smaller volume of lake water than during the summer months. This is explained partly by the increased quantity of dissolved oxygen in the lake water and partly by the lessened oxygen demand of putrefying sludge deposits. It led to a statement that "regulated dilution" whereby the flow would be regulated at different seasons would be more advantageous to all concerned than would be a uniform rate of flow whereby needless diversion of lake water would occur during the winter notwithstanding that during the summer there would be an oxygen deficiency for many miles in the canal and river system below.

In streams where the natural flow is unaided by diverted lake water, such regulation is not feasible, and it is necessary to consider the oxygen balance at times of smallest stream flow.

RESIDUAL OXYGEN

As earlier explained there is no need of a substantial quantity of residual oxygen in a stream in order to prevent nuisance due to putrefaction, provided that some oxygen is present at all times and in all places so as to prevent anaerobic decomposition with its attendant bad odors.

There is no justification from the nuisance standpoint for asserting that, so far as residual dissolved oxygen is concerned, there should be a margin of 33 or 50 or 70 per cent of that needed for saturation at given temperatures, as may be deduced from Table 36.

New York Harbor.—The Metropolitan Sewerage Commission of New York placed the limit at 3 cubic centimeters of oxygen per liter (4.3 parts per million), equal in the local harbor water to about 58 per cent of saturation. Allen in his 1918 report to the city officials of New York states that to insure a safe margin in the main body of New York Harbor the dissolved oxygen should not become less than 30 to 50 per cent of saturation, depending upon various local conditions and including the amount of sludge deposit on the bottom. He recognizes the influence of the evolution of oxygen consuming gases from decomposing sludge deposits and that putrefactive odors are not produced in water so long as there is everywhere a residue of dissolved oxygen. It is large volumes of septic sewage and decomposing sludge deposits that cause objectionable odors to occur notwithstanding the presence of dissolved oxygen in much of the over-lying water. Allen further states that, for the preservation of major fish life, the water should contain not far from 50 per cent saturation of dissolved oxygen.

Fuller advised the Metropolitan Sewerage Commission of New York in 1914 that a dissolved oxygen content of 25 to 35 per cent of saturation, equal to about 1.5 cubic centimeters per liter, or 2.5 parts per million, was reasonable provided complications from decomposing sludge deposits could be kept under control. Without such control it is difficult to generalize on this question, as each situation has its own individuality.

London Experiences.—The lower Thames since about 1892 has received the London sewage after the removal of a great portion of the settleable solids. Prior to the adoption of chemical precipitation conditions were very objectionable. Extensive investigations in recent years have shown that the dissolved

oxygen may become as low as about 10 per cent of saturation without objectionable conditions developing. In fact, evidence indicates that dissolved oxygen at times becomes somewhat less than this amount without odors being noticeable away from the stream itself. It must be remembered in noting such information that decomposing sludge beds are not a substantial factor in the lower Thames.

Residual oxygen in the lower Thames, ranging say from 5 to 15 per cent of saturation, seems to be reasonably adequate to prevent nuisance. The local authorities are considering procedures to provide for fish life.

Philadelphia Experiences.—At Philadelphia it was found that in the Delaware River opposite the center of the city and about 500 feet from shore, the dissolved oxygen during 1912 was reduced to an average of less than 20 per cent of saturation between July 1 and September 20. Notwithstanding this low oxygen content, there was no odor noticeable in this stretch of water.

In Germany in 1912 viewpoints coincided quite closely with those herein stated.

In the event that American communities eliminated excessive existing sludge deposits and prevented the accumulation of future deposits, it would probably go a long way towards harmonizing viewpoints in conformity with what practice has shown at London, Philadelphia and other places.

OXYGEN REQUIREMENT OF FISH LIFE

When it comes to requirements of major fish life, the question of residual oxygen requires a different view. Carp and some hardier forms of fish life require only comparatively small quantities of oxygen, and trout and some other forms do not hesitate to enter waters containing 1 to 2 cubic centimeters per liter.

SEASONAL EFFECTS

At the warmer temperatures of the spring and summer, biological activities are greater than during the winter. More oxygen, therefore, is required during the summer than during the winter in order to maintain the oxidation of organic matter on a satisfactory basis, when the time interval is the same.

In this connection, it is of interest to note the dissolved oxygen content of the Merrimac River at Lawrence, Mass., where it still serves (1926) as the source of the city water supply after filtra-

tion. The data in Table 40 are copied from Kinnicutt, Winslow and Pratt, as illustrative of conditions where bad odors occur at times of low summer flow. It is correctly stated by these authors that while any dissolved oxygen remains, there should not be "putrefaction." But they add that practically any value below 50 per cent of saturation is likely to be accompanied at times by malodorous conditions. This last statement should not be interpreted too rigidly as applicable to problems where sludge deposits are eliminated and reasonably complete mixture of the sewage with the water is provided. It accentuates, however, a result that is found at some places where improper mixing causes shore pollution and where stranded sewage solids produce offensive deposits.

Table 40.—Seasonal Conditions in Merrimac River at Lawrence, Mass.

Month	1899			1900		
	Flow per 1000 persons discharging sewage, (second-feet)	Temperature, ° F.	Dissolved oxygen, (per cent of saturation)	Flow per 1000 persons discharging sewage, (second-feet)	Temperature, ° F.	Dissolved oxygen, (per cent of saturation)
Jan.	42.6	34	96.3	18.2	33	81.6
Feb.	26.4	34	88.1	89.1	34	87.8
Mar.	64.5	34	95.6	87.7	35	
Apr.	143.2	..	99.3	100.0	41	99.1
May	51.6	58	84.4	54.1	54	
June	16.1	73	71.1	21.4	73	62.1
July	13.4	76	66.6	9.8	77	59.4
Aug.	11.3	74	58.3	10.1	75	43.6
Sept	10.8	67	57.2	8.2	71	32.5
Oct.	9.7	58	53.7	13.6	62	47.6
Nov	15.1	40	78.1	31.6	46	91.2
Dec	15.1	36	84.3	36.6	38	98.0
Average	34.5	53	77.8	39.9	53	70.3

TIME AND DISTANCE FACTORS

As is true of the incubation or putrescibility test, the factor of time is of much importance in the deoxygenation and self-purification of rivers by bacterial action.

If the Chicago drainage canal were one-tenth of its present length and then discharged into the Mississippi River, it would produce a better result than now obtains, as to deoxygenation in the canal, but the oxidation of organic matter would be less complete, because of the shorter time interval.

On the other hand, if it should flow for ten times its present length at the same velocity, uninfluenced either by the diluting water or the pollution of the Illinois valley, then the anaerobic decomposition would probably make odors far more pronounced than now exist.

The lower Mississippi River gets the benefit of this long time interval and shows the result in the completeness of the self-purification. In short streams that are not over-loaded, the time factor is too short to show much improvement in the water.

When the degree of dilution is adequate, the self-purification of the stream on an aerobic basis will become more complete as the time interval increases. But if the dilution is inadequate, then the factor of time shows itself, first, in the establishment of anaerobic activities with the exhaustion of oxygen; and, secondly, in the degree to which putrefaction proceeds.

It is important to keep in mind that the initial oxygen will not necessarily remain a constant. As the population increases in the upper valley, the initial oxygen in the water of the middle and lower stretches may materially lessen.

Likewise reaeration effects on the river water will not increase proportionately with the population, although the rate of reaeration may, for the latter is an inverse function of the degree of saturation of dissolved oxygen. However, reaeration is likely to decrease if the water surface is more or less covered with "sleek."

Conditions also may be progressively aggravated as time goes on because sewage mud accumulates year after year at some places, to undergo anaerobic decomposition and deoxygenate the over-lying water to some extent.

CHAPTER XI

PLANKTON: BIOLOGICAL BALANCE

SYNOPSIS

1. Description.—Plankton are small forms of animal and vegetable life suspended or swimming in water. The more usual American expression is perhaps "microscopic organisms," which strictly speaking is a broader term including organisms found on the bottom and sides of stream beds and on obstructions in watercourses. Neither of these general terms is intended to include the bacteria, although doubtless there are some filamentous bacteria which might be so included when they produce masses that may be identified under the microscope.

2. Index Organisms.—Certain groups of plankton have such definite characteristics as to food supply and other environmental conditions that the general quality of water may be approximately registered by noting the prevailing forms of microscopic life. Thus, there are index or type organisms which will reveal distinctions between septic, polluted, contaminated and clean waters.

3. Present Status.—Important investigations as to plankton were made at a number of places particularly in Germany, Illinois and Wisconsin, prior to the interruptions in technical activities during the World War. Since then such investigations have been resumed, especially by the United States Public Health Service, and more attention has been given in America to this means for measuring the quality of water. For problems of magnitude it is an item for careful consideration, although it is probably too early to generalize on its applicability per se or in combination with other means of measuring limitations in the dilution method of sewage disposal, in the sense of relative reliability and economy of methods of investigation. American observers regard plankton studies as helpful, but rarely of controlling importance.

4. "Balanced Aquarium."—A condition is constantly evolving in some watercourses wherein plant life assimilates the nitrogenous

material excreted by animals. Such material through bacterial action is oxidized so as to serve more readily as a food for plant life, which also consumes carbon dioxide coming largely from animal respiration. Diatoms, algae and some other plankton produce oxygen which supplements that absorbed from the atmosphere. Thus there is produced plant life which serves as food for the smaller animal life which in turn sustains fish life. It is entirely reasonable to include mankind in this cycle in dealing with the sewage question, because in sewage polluted streams the plankton derive additional quantities of food from sewage and thus produce in never-ending series a cycle which constitutes an important factor in the economy of nature, and which produces food for human consumption.

5. "Biological Balance."—This expression relates to approximately such conditions as are involved in the "balanced aquarium" described above. Plankton are revealed in some watercourses where there is substantial coordination between those which may be classed as food producers and food consumers, respectively. Over-pollution of a stream disturbs such biological balance and adds another limitation to the dilution method. On the other hand, where the disposal of sewage by dilution is reasonably taken care of by biological agencies, it adds to the economies of nature in that it satisfactorily disposes of waste products and actually enhances the values found in watercourses through production of food for human consumption.

HISTORICAL DEVELOPMENT

"Plankton" strictly speaking is the expression used to designate the small forms of animal (fauna) and vegetable (flora) life which are suspended or swimming in water. Prior to the World War, considerable progress had been made in studying these organisms as an index to the degree of pollution of streams. Different groups of small aquatic life have definite characteristics as to food supply and other environmental conditions. Within certain limits the quality of some waters may be approximately registered by noting the prevailing forms of microscopic life.

American Experiences.—In America the work of Sedgwick, Rafter, Whipple and others aided much in the advancement of our knowledge of microscopic organisms. This expression is a broader one than that of plankton, as above given, in that it deals

with the attached organisms found on the bottom and sides of stream beds and on any obstructions in the watercourse. American sanitarians include in microscopic organisms all forms of small animal and vegetable life other than bacteria, although the latter are also included with the microscopic organisms when filamentous bacteria produce masses that can be identified and enumerated readily under the microscope.

This explanatory statement as to American practice would not be complete without reference to the highly important work which for more than 30 years has been an outstanding feature of the water laboratories of Boston, New York and other cities deriving similar supplies from impounding reservoirs. These investigations in matters of water supply have been of great help in studying the conditions related to objectionable tastes and odors due to microscopic growths and means for their prevention.

Careful investigations of the microscopic growths in polluted waterways have been conducted particularly on the Illinois, Potomac and Ohio Rivers and tributaries. The work of Kofoid, and of Forbes and Richardson of the Illinois State Natural History Survey are well worthy of detailed study. The same is true of the reports of Purdy, Plankton Expert, United States Public Health Service, especially Hygienic Laboratory Bulletin No. 104 and Public Health Bulletin No. 131, dealing with the plankton and related organisms of the Potomac and Ohio Rivers, respectively.

German Practice.—In Germany prevailing views[1] as to the most advantageous practice for rating the degree of pollution of surface waters by means of plankton were set forth in 1911 with later extensions as to observations by Kolkwitz.

It is important to record the fact that for many years German investigators have used plankton observations with considerable success as indices of stream condition. More than 15 years ago, the presence of sphaerotilus, carchesium and leptomitus in tributaries of the Rhine and the Main was found to be indicative of excessive organic loadings of streams, even where dissolved oxygen conditions were favorable, according to chemical tests. The same occurrences have been observed, within the past few years, in the lower Rhine, with the same organisms, where this river passes into Holland. Kessener, of Holland only recently

[1] Those views as translated by Kuichling in Engineering News, October 31, 1911, are also summarized in Fuller's Sewage Disposal, pp. 264 to 275.

referred to the objectionable effects of these organisms upon the fishing industry, due to remarkably rapid clogging of fish nets.

The striking feature of his observations, as well as the earlier German experience, is that these plankton result from heavy organic loads, occur in the presence of oxygen in the stream, and hence are neither detected nor measured by current chemical tests for dissolved oxygen.

Since the World War continuance of these investigations has again brought this subject to the front in a conspicuous way and advocates of this means of measuring pollution point to the greater readiness with which an opinion may be reasonably formed as to the condition of some streams as compared with the time and expense involved in making a large number of chemical tests involving oxygen demand and estimates as to oxygen balance to be expected under the widely varying ranges encountered on many river systems.

The plankton experts indicate that at best oxygen tests or other chemical tests simply record the condition at the moment when the sample was collected from a particular location. Plankton investigations, they say, will record on a more comprehensive basis general conditions as to water pollution by taking into account the food, pollution and various elements of environment on a seasonal basis rather than for the instant represented by the collection of the chemical sample. Further, plankton studies give a mass record of stream condition as a whole for a season or a period of substantial duration. Such studies offer a full life history of activities along many lines related to pollution of streams, whereas chemical samples correspond to a bulletin of an instant day and cannot be made into a complete history without the time and expense of a multiplicity and repetition of tests.

For many important streams it is wise to have the aid of all the observations which may be secured from both the chemist and the plankton expert. The frequency with which large American rivers are very turbid or muddy for weeks and months at a time probably restricts somewhat the scope of promising investigations as to microscopic organisms. Nevertheless as knowledge increases as to the classes of microscopic growths which characterize rivers of varying degrees of pollution, the more readily will advantage be taken of plankton as a means of rating the quality of many smaller streams, and as recording the range of pollution, at different stages and seasons, of large river systems.

INDEX ORGANISMS AND THEIR CHARACTERISTICS

When plankton investigations are carried on most advantageously they relate to the detection of index organisms which are definitely known either to prefer or to avoid a polluted environment. With such organisms are found, of course, many other types which have no such definite positive or negative reaction to pollution.

Pollutional organisms are designated as those which grow readily in heavily polluted water and the cleaner water organisms are those thriving in relatively clean water.

The German studies of Marsson and Kolkwitz led to the classification of streams into three zones with a subdivision to the middle zone or practically four zones starting with first polluted water and moving through two intermediate stages to the final stage in which self-purification has passed beyond the immediate sewage pollution phases. We give the classification as translated by Kuichling in order to record the characteristic organisms designated by the original investigators.

MARSSON-KOLKWITZ CLASSIFICATION

Polysaprobic Zone.—Characterized by multitudes of Schizomycetes (bacteria), bacteria-eating Flagellata and Ciliata.

From a chemical standpoint this zone is also marked by the predominance of reducing and splitting processes due to lack of dissolved oxygen and to the excess of carbonic acid; also to relatively high content of decomposable food matters, which is indicated by the growth of certain organisms that may be regarded as living reagents.

Mesosaprobic Zone.—The process of decomposition has advanced to an intermediate degree. For convenience this zone will be divided into two parts, called A-mesosaprobic, and B-mesosaprobic, the first extending up stream and adjoining the polysaprobic zone, and the second extending down stream and adjoining the clean-water or oligosaprobic zone. The first part is usually characterized by the appearance of Schizophyceae and Eumycetes, along with Anthophysa vegetans, Stentor Caeruleus, Carchesium lachmanni, etc. Many bacteria are still present. Drainage ditches carrying imperfectly purified water are good examples of A-mesosaprobic zones. The B-mesosaprobic zone is generally distinguished by its contents of Diatomaceae and certain Chlorophyceae, along with Rhizopoda, certain Ciliata, Vermes, numerous Rotatoria, etc.

Oligosaprobic Zone.—Hygienic interest in the disposal of sewage generally terminates at this zone, while it begins herewith in the case of domestic water supplies. The chief characteristic of this zone is the completion of the process of mineralization; all of the more or less turbulent processes of self-purification are absent in the water itself, and the biological development is usually extensive. The appearance of certain representatives of the

Peridiniales, all Charales, and certain planktonal Cilia, Rotatoria, and Crustacea are to be regarded as characteristic.

FORBES-RICHARDSON CLASSIFICATION

The Natural History Survey of Illinois published in 1913 an excellent report by Forbes and Richardson on the biology of the upper Illinois River. These records show changes in biological conditions as compared with the earlier Kofoid investigations due to the effect of additional sewage from the Chicago district. One of the principal objects of the later investigations was "a description of the criteria and effects of different degrees of contamination of the natural waters of the Illinois."

Following the plan of Kolkwitz and Marsson, Forbes and Richardson divided the Illinois river system under investigation into four sections which they designated by the terms "septic," "polluted," "contaminated" and finally "clean water." A summary of their findings, somewhat abbreviated, by Purdy in Public Health Bulletin No. 131, is well worthy of study, in that it shows the plankton and other characteristics in four zones of pollution through a stretch of 107 miles beginning with the terminus of the Chicago Drainage Canal.

While the biological characteristics noted by Forbes and Richardson are of great importance in considering the self-purification of this highly polluted watercourse, through a long stretch of its turbulent portions and lake sections with low velocities under conditions such as to bring about real purification through natural agencies, it is not to be inferred that the results in question are readily applicable elsewhere. In the first place many streams are far too short to produce a time interval sufficient to accomplish the self-purification represented by the four zones here noted. Furthermore, rivers like the Ohio have their decided complications incident to heavy turbidities and enormous ranges in velocities of flow with floods at certain seasons of the year and relatively slack water in canalized portions at other seasons.

PURDY'S CLASSIFICATION ON THE POTOMAC

The plankton studies set forth in Hygienic Laboratory Bulletin No. 104 as a part of the investigations by Cumming of the Potomac Watershed are well worthy of record. They show conditions with relatively small pollution above Washington, the

pollution incident to the Washington sewage entering the turbid river, which flows through a stretch of tidal flats, and finally enters the tidal estuary where the upland water became relatively clear after adequate mixture with more or less sea water of Chesapeake Bay. Purdy followed the Forbes and Richardson method of four stages as to character of water and likewise defined their biological characteristics.

The principal reason for referring to these classifications is to record the index organisms and biological characteristics in the Potomac as a result of the investigations detailed in Bulletin No. 104.

It will be of aid to note that for septic water it is stated that the water was discolored with offensive odors and gas bubbles arising from the bottom on which was sticky dark-colored mud. The dissolved oxygen content ranged from 0 to 20 per cent of saturation, CO_2 was high, as were the ammonias and nitrites.

The polluted or Zone 2 stretches were physically like those of Zone 1 during the summer and varied only in degree. Dissolved oxygen content ranged from 15 to 60 per cent of saturation. Zone 3, contaminated water, showed 70 to 100 per cent of dissolved oxygen saturation with no odor, discoloration or bubbles. Bacteria growing at 20° C. ranged from 100 to 5000 per cubic centimeters B. coli present in 1 cubic centimeter and sometimes in 0.1 cubic centimeter.

Zone 4, or clean water, gave no physical indication of pollution. Dissolved oxygen was usually at the saturation point. Total bacteria count at 20° C. ranged from 100 to 1000 per cubic centimeter. B. coli was usually present in 10 cubic centimeters but not in 1 cubic centimeter.

Without attempting further generalizations as to the characteristic plankton found in the several zones, reference is here made to the reports for further details revealed by these investigations.

ORGANISMS IN MUDDY OOZE OF LAKE BOTTOMS

Extensive investigations of the biology of the Wisconsin lakes were published as Bulletin No. 22 of the Wisconsin Natural History Survey in 1911. These summed up the results of some 10 years studies by Birge and Juday. These studies were not related so much to sewage pollution, although organic matter entered some of the lakes which had a depth sufficient to become stratified during warm weather. In consequence there was a

zone at the bottom in which there was no free oxygen. Studies in Lake Mendota showed a record of value as to organisms growing under anaerobic conditions in muddy ooze as follows:

The Protozoa were represented by the largest number of forms. Living, active representatives of sixteen genera have been noted, Pelomyxa, Difflugia, Colpidium, Gyrocoris, Peranema, Coleps, Loxophyllum, Paramecium, Prorodon, Lacrymaria, Uronema, Monas, Metopus, Spirostumum, Loxodes and Stentor. All of the individuals representing these genera were perfectly normal so far as could be determined. They showed no evidences of unusual vacuolation, or any other signs of ill effects resulting from the anaerobic conditions under which they lived. Some of the parasitic protozoa constantly live under practically anaerobic conditions, so it is not surprising, perhaps, that the above forms should adapt themselves to such conditions when necessary. These anaerobic conditions exist in Lake Mendota for a period of about 3 months each summer, and it has been found that these protozoa are as numerous and as active toward the end of this period as at the beginning. Apparently, then, these organisms are able to carry on their life processes just as well under anaerobic as under aerobic conditions.

Higher invertebrates were also found in this muddy ooze. The worms were represented by specimens of Tubifex, Limnodrilus, and Anguillula; the rotifers by Chaetonotus and Philodina; the crustacea by an ostracod belonging to the genus Candona and by encysted specimens of Cyclops bicuspidatus; insect larvae by a large red chironomid larva; and the mollusca by Corneocyclas idahoensis.

These studies are of real practical significance in that they indicate what forms may be expected on the bottom of rivers and lakes related to sewage pollution. Thus at Toledo the effect of the local sewage at and near the mouth of the Maumee River and in Maumee Bay was far more readily traced by the presence of red worms than in any other way. Although during calm weather bacterial conditions in the ooze at the bottom of the lake were no doubt on an anaerobic basis, samples of over-lying water showed ample content of dissolved oxygen and no visible signs of sewage pollution. A different situation, however, would prevail following heavy windstorms in respect to the influence of such sewage solids from the standpoint of pollution of bathing beaches or waterworks intakes some distance away.

RELATION TO OXYGEN BALANCE

Plankton have a direct relation to oxygen balance as discussed in Chapter X. Some micro-organisms are known to produce oxygen and others to consume it.

Oxygen producers are those organisms that contain chlorophyll or its equivalent, and are known to be plant-like in their life processes, thereby consuming in respiration a minimum of oxygen, but during sunlight giving off a great excess of oxygen by the process of assimilation or photosynthesis. This includes all plants except the fungi and the bacteria. It also includes such of the mastigophora, or flagellates, as contain chlorophyll.

Oyxgen consumers are those organisms that consume oxygen by respiration; but, lacking chlorophyll, they have no photosynthetic action as plants have, do not require light, and do not produce oxygen. The fungi and various animal forms, such as rhizopods, colorless flagellates, the ciliates, the rotifers, crustacea, and minute worms, are thus classed as oxygen consumers. It should be borne in mind that plankton data necessarily cannot include various classes of bacteria, many of which are heavy consumers of oxygen. The plankton are important, however, in their marked ability to consume bacteria.

All plankton values are stated in terms of *cubic standard units*, a volume represented by a cube 20μ on the edge. Very often several of the smaller organisms are required to make up a volume equal to one cubic standard unit. On the other hand, a single large organism, such as a rotifer or crustacean, may measure several hundred standard units. Obviously the only way to put these organisms of all sizes on a comparable basis is to express their values in terms of volume. This has been done in all cases. The single word unit is frequently used for the sake of brevity. Dividing the number of standard units per cubic centimeter by 125 gives results in *parts per million by volume*.

CHAPTER XII

LAKES, OCEANS AND TIDAL ESTUARIES

SYNOPSIS

1. Comparison of Conditions.—The natural laws governing the disposal of sewage by dilution are generally applicable to disposal in lakes, oceans and tidal estuaries. New and peculiar problems, however, arise in these larger watercourses which do not occur normally in inland streams. For the sake of explicitness, these features are discussed here separately. In the use of public water supplies derived from lakes, there is, of course, a point of similarity with inland stream conditions, but more significance is attached to pollution of these larger watercourses by oil and sleek in relation to public bathing beaches and pollution of shellfish layings in the case of salt and brackish waters.

2. Lake Characteristics.—Large lakes differ from most rivers in that the water is generally of much greater clearness, thus allowing sunlight to penetrate so as to facilitate the growth of certain plankton which do not thrive in turbid river waters. Fresh-water lakes show thermal stratification due to temperature differences above and below a plane which separates the water which is disturbed by wind action from that which is not so disturbed. Lake bottoms show the effect of sedimentation of settleable sewage solids, but severe windstorms will stir up and move such sediment in waters to a depth of 40 feet or more.

3. Translation Currents.—In large lakes currents due to the movement of water toward the outlet are practically negligible. Tides become an important factor for consideration in the disposal of sewage in oceans and tidal estuaries. Winds assume controlling importance in many cases, because high velocities may drive polluted surface water for many miles. Currents introduced by winds are extremely variable both as to direction and intensity. Irregularities of currents require consideration of "undertows" and undercurrents whereby the direction of flow is

upset or where the flow of bottom waters is at variance with that of top waters.

4. Brackish Water.—Diluting water in tidal estuaries is not limited to the fresh water from upland streams, but includes ocean water. The determination of the latter influence involves the calculation of the "tidal prism," a volume equal to the area of the estuary in question multiplied by the rise of the tide. By the "piston method" there is computed for the given conditions the approximate frequency with which the particular body of polluted water is displaced by clean water. This problem is complicated and requires special study for each situation. Salt water has a higher specific gravity than fresh water.

5. Dissolved Oxygen.—Salt water when saturated with atmospheric oxygen contains perhaps 80 per cent as much oxygen as fresh water at the same temperature. Salt water shows a tendency to precipitate or to coalesce the non-settleable solids of the sewage. Hence sewage sludge may be greater in amount when diluted with salt and brackish water than in fresh water. Furthermore the high content of sulfates permits polluted salt water under certain biochemical conditions to produce more hydrogen sulfide and foul smelling products than fresh water.

6. Salt Water Vegetation.—In brackish water are found distinctive flora of bacteria and miroscopic organisms, as well as certain types of "seaweed." These with the sewage mud on the bottom of salt or brackish water will exhaust atmospheric oxygen from the over-lying water with greater relative speed than in the case of fresh water, other things being equal. Tidal action with its rapidly changing water levels causes in some instances an exposure at low tides of mud-covered flats with resulting complications as to odors not usually encountered in lakes with their more constant water levels.

7. Salt Water Underrun.—The bottom water in some tidal estuaries is more salt than the top water due to the "underrun" of clean ocean water. This should be borne in mind in considering biochemical activities. It should also be remembered that, in fairly deep estuaries, the tide does not turn at the same time at the surface and bottom of the water. Thus in the same vertical plane transverse to the main current there is always some velocity of flow to promote the dispersion of sewage discharged near the bottom of the estuary.

GENERAL STATUS

The foregoing chapters apply more particularly to the dilution method for inland streams, but disposal of sewage in large bodies of fresh, salt or brackish water is also widely practiced. As with rivers, this procedure has its limitations. When carried out reasonably and intelligently, however, it is a suitable and proper method. Ultimately all sewage reaches the ocean. The problem is how to regulate such uses of large bodies of water without injury to the public health or creation of objectionable nuisances. Obviously the solution lies in advantageous adjustment to local conditions, after careful investigation, and in supplementing the dilution process by treatment works as they become necessary or desirable to avoid over-balancing the capacity of the receiving water.

FLOATING SOLIDS

Sewage should be substantially freed of floating solids of obvious sewage origin. To deal with the problem adequately, it is further necessary to protect watercourses from the floating litter which comes from garbage, street wash or the rubbish which so frequently is disposed of along the water front by throwing it into the water. The discharge of wastes from steamers, tug boats and other fairly large craft in harbors, as well as the solid refuse now so generally thrown overboard from house boats and small craft in sheltered coves near yacht clubs or other landing stages, create serious difficulties.

In several instances, conspicuous examples have been noted of lack of cleanliness in watercourses from which city sewage has been removed. This branch of the task of cleaning waterways requires thorough, systematic efforts as have been provided at London and elsewhere in Europe where the harbors and water fronts are policed in boats to see that the occupants of all boats of all sizes comply with reasonable rules governing the discharge of solid wastes into receptacles which may be emptied from time to time without undue inconvenience to boatmen.

Until municipalities, however, free adjacent watercourses from visible sewage solid matter, it is difficult to carry out effective policing rules for other important purposes.

OIL AND SLEEK

Many harbors show objectionable quantities of oil and sleek which is the greasy film noticeable on the surface of sewage

polluted water. Such sleek is found in watercourses polluted with normal city sewage, but it increases, of course, with the amount of oil disposed of in the sewers.

Conditions in this respect have changed materially during the past few years due to the installation of oil-burning arrangements in many steamers, the increasing numbers of large oil refineries and the lubricating oils wasted into the sewers from garages and other plants using large quantities of lubricants. In several cases, accumulation of oil on harbor waters has resulted in serious conflagrations.

Discharges of oil have also brought about objectionable situations on bathing beaches and interference with all forms of fish life, through the deposition of oil sludge on the bottom of waterways and the filming of other areas. Instances have likewise been reported where the presence of oil on certain waters which were used as sources of domestic water supply have resulted in recourse to more polluted sources.

These situations in general became so aggravated about 1922 that widespread propaganda was set up to eliminate many of the oil-contributing wastes as a final desideratum. These discussions were made the primary objects of programs of fish and game associations, conservation commissions, fire departments and general harbor pollution prevention organizations. After several years of such activities in the press, in public meetings and in scientific associations, it was soon indicated that the solution of the matter involved some form of national legislation, inasmuch as the spread of these wastes was not restricted to municipal or state boundary lines. In view of these circumstances, Congress was finally prevailed upon to enact a federal anti-pollution act which prohibited the discharge of oil wastes from water craft of all kinds. Although an effort was made to include in this legislative enactment a similar provision against the discharge of oil wastes from plants on land, this effort was not successful, probably because so many of the states had ample powers and personnel to control the situation on land. The discharge of these wastes from water craft had assumed likewise an international aspect so that legislation of a similar character was passed by other countries either before or after that put into effect by the United States Government. Considerable improvement in the situation has resulted from these public discussions and from the limited amount of federal legislation which was

passed to meet specific problems. Further discussion of this problem has reached international proportions, for in June, 1926 an international conference on oil pollution was called in Washington to determine upon uniform legislation for maritime nations. The situation is amplified here because it illustrates the legal, administrative and jurisdictional difficulties which may confront one in the attempt to control and to order wisely the nature and degree of treatment of particular groups of waste materials.

HYGIENIC ASPECTS

The discharge of sewage into large lakes gives rise to the same form of hygienic complications as described in Chapter VIII. Currents due to wind action and the factors which are mentioned later on in this chapter, as peculiar to lakes, oceans and tidal estuaries, emphasize the increasing complexity of the use of lakes for disposal of sewage.

In Chicago, the growing popularity of bathing beaches is indicated by official records showing attendances respectively for 1920, 1921, 1923 and 1924 as 1,035,460, 2,082,917, 3,010,000 and 3,642,300. In addition to these uses, some of the largest and best appointed hotels have recently been constructed on the lake front with private accommodations for beach bathers. This condition is typical of dozens of similarly situated cities. Where the health of millions of individuals is involved in such enterprises, the public health significance of these facts should not be underestimated. That such situations have a definite epidemiological basis has already been stressed in Chapter VIII on Hygienic Aspects.

Here reference should be made again to the fact that a large number of sewage disposal undertakings owe their origin in part to the public demand for safe and protected bathing beaches.

As has already been pointed out, shellfish layings in tidal estuaries continue to be an important hygienic aspect of sewage disposal. With the general increase throughout the country in the number of water filter plants which are gradually placing the quality of public water supplies above suspicion, sanitarians in many localities are now beginning to be able to trace residual typhoid fever cases to polluted shellfish more successfully than hitherto, when such cases were concealed in the much greater total of water-borne typhoid fever. The recognition of these

considerations has likewise resulted within the last 2 years in rapid and important changes in sanitary and administrative procedures.

STRANDED SOLIDS

While floating solids are bothersome in many waterways, and it is well known that sludge banks are frequently to be found in the general vicinity of sewer outlets, it is realized that currents will move settling solids of sewage origin for substantial distances. In fact bathing beaches in some localities have had their usefulness eliminated or largely reduced as a result of sewage matters becoming stranded on the beaches. In instances where there is gross pollution, the sewage solids are quite noticeable, but there are other places where "grease balls" are found upon the beach at a considerable distance from any sewer outlets.

In the general field of sanitation this question deserves and is receiving much more attention than formerly.

CURRENTS

Most rivers have a well defined current, although there may be interruptions at times of dry weather in the case of small watercourses, particularly where there are mill ponds. In many cases where the dilution method is used on large rivers, great benefit is derived from well defined currents which prevail at all times.

In large fresh-water lakes, translation currents due to the water moving forward to the outlet are so small as to be negligible. Wind currents, however, at intervals produce currents in large lakes varying both in direction and in intensity. Such irregularities add a real complication. During the calm weather which prevails sometimes for days and weeks, conditions may occur which, when investigated, lead to conclusions which furnish no accurate criterion whatever as to the reliability of the dilution method, as far as its influence upon the quality of water at more or less distant waterworks intakes or bathing beaches is concerned.

Complications further arise frequently as a result of top and bottom currents being in opposite directions. Thus a wind blowing from the shore on to a lake naturally drives the surface water away from the shore, but the undertow or bottom current is toward the shore. Reverse currents appear even more strikingly when the wind comes from the lake to the shore. With an irregular shore line, numerous intricate and complex results

are naturally produced. It is difficult and not always possible to study all of these irregularities of currents at times of their greatest significance, on account of dangers attending their study when high wind velocities prevail on large lakes, but a realization of their occurrence is an important aid in reaching logical conclusions as to procedure.

Tides produce well defined currents in the oceans and tidal estuaries. They too are influenced materially by wind and have their complications due to "underrun" of salt water and undertow as just explained in connection with inland lakes.

STRATIFICATION

When undisturbed by wind action, a difference of about 2.5° F. in the temperature of water causes sufficient variation in density to result in stratification. This varies in different lakes depending upon the latitude in which they are situated as well as on their area and depth. In the lower stratified portions of lakes there is a zone of decomposition in which bacterial activities occur on an anaerobic basis. This is found in lakes which are unpolluted. It is to be borne in mind, however, that at intervals, particularly during the spring and fall, there is a vertical circulation in lakes of this type, and pollution from sewage may, on such occasions, be driven to waterworks intakes or other locations unaffected during periods of fairly quiescent stratification. However, in most cases lakes have a sufficiently flat slope to the bottom so that most of the complications as to sewage pollution relate to top water above the zone of decomposition.

In bodies of salt water it is necessary to recognize the greater specific gravity than that of sewage unmixed with salt water. This has a tendency to facilitate the separation of the sewage as a surface layer over-lying the denser salt water. It accentuates the importance of thoroughly mixing the sewage with the receiving water, as was especially investigated for the Passaic Valley outlets in the upper New York Bay, described in Chapter XIII.

In tidal estuaries the bottom water frequently contains an underrun of salt water from the ocean which adds to the diluting capacity of the estuary, if the sewage is mixed with bottom water. In the absence of such mixture the absorbing capacity is likely to be less than that which might be reasonably anticipated, particularly if little or no effort is made to prevent the lighter sewage from being confined to the upper layers.

In deep estuaries such as in the channel of upper New York Bay there is an appreciable difference in the time when the tide turns as regards top and bottom water. This means that, in a vertical plane, there is no time when the water is quiescent and without velocity. Thus with bottom outlets the discharge of sewage as it rises upward will encounter moving water due to tidal action, even at the instant when there is no tidal movement in the bottom water.

In attempting to estimate the quantity of diluting water in tidal estuaries, it should be borne in mind that this is not restricted or limited to the amount of fresh water which has its origin in upland streams. Owing to the topographical layout of such estuaries a considerable, but varying, proportion of their waters is made up of ocean water brought in or carried away with the changing tides. The determination of the influence of ocean water upon tidal diluting capacity of estuaries requires the calculation of the so called "tidal prism." The tidal prism is that volume of water which is equal to the area of the estuary multiplied by the rise of the tide; in other words, it is the contribution to the volume of the estuary made by the incoming tides. In order to determine the instantaneous volume of estuarial water under given conditions of tidal currents, it is necessary to calculate the approximate frequency with which the particular body of polluted water is displaced by clean water. The analogy to the calculation of piston displacement will make clear to the reader the physical phenomena with which we are concerned and will clarify likewise the method of calculation of diluting capacity under varying conditions.

WIND ACTION; BOTTOM SCOUR

Winds will produce velocities of importance and at times move polluted lake water for several miles, as already noted in the discussion of currents.

Wind action is variable both as to direction and intensity. This means substantial irregularities in sedimentation, causing deposits to appear on the bottom of the lake in a variable way within the limits of areas where there is disturbance by winds during severe storms.

In the Great Lakes wind action will produce bottom disturbances sufficient to move sewage sludge to depths of 40 feet or more. Observations show that following heavy windstorms a clean lake

bottom to these depths is observable, and at greater depths are found the usual deposits of sewage mud and other decomposing material. Between such storms, the bottom of the lake will show deposits of sewage solids depending upon the volume of entering sewage, the extent of removal therefrom of settleable solids and other factors.

As explained in connection with currents, bottom scour is likely to be more active in the opposite direction from that of the wind. This explains some observations which are otherwise perplexing.

In tidal estuaries, particularly at times of storms, winds and tides combine in some places to produce scouring velocities, which are ordinarily absent in bodies of salt or brackish water receiving sewage.

CHEMICAL PRECIPITATION

Salt water coalesces finely divided or colloidal organic matter in sewage. In estuaries where the water is naturally turbid this is not much of a factor, but it is worth keeping in mind in those instances where it is desirable to avoid appearances of sewage pollution and where selection is to be made of a treatment method.

OXYGEN BALANCE

The statements as to oxygen balance in Chapter X hold generally true for lakes and estuaries, except that the amount of dissolved oxygen at the same temperatures is about 20 per cent less in brackish than in fresh water, thus modifying the oxygen demand of a given amount of organic matter.

The amount of residual oxygen necessary for the survival of major fish life is believed to be quite similar in both fresh and salt waters.

As to bacterial decomposition processes, it is to be pointed out that, other things being equal, a given amount of sewage will give greater offense when it is mixed with a given volume of brackish water than with the same amount of fresh water. Apparently this is related partly to the proportionately less available dissolved oxygen, but perhaps also to the decomposition of mineral sulphates and the formation of hydrogen sulphide.

PLANKTON

Lakes, oceans and tidal estuaries naturally contain clearer water than found in most American rivers. Brackish water

brings in new groups of plankton, as well as certain types of "seaweed," which in themselves produce offensive odors of decomposition, if stranded at low tides upon exposed mud-covered flats.

PROGRESS IN AMELIORATING CONDITIONS

The discussion of the foregoing difficulties which have confronted municipalities and other aggregations of population in the disposal of sewage in lakes, oceans and tidal estuaries would not be complete without referring to at least some of the outstanding examples of where these difficulties have been partially or completely met. Much progress has resulted in the last 20 years in eliminating sources of contamination of these watercourses through various engineering and administrative expedients. It is not only interesting, but it is highly important, in recognition of real accomplishment in the past two decades, to set forth briefly herein some of these achievements, which involve municipal, state, federal and international aspects.

EXPERIENCE ON THE GREAT LAKES

Important history has been made in connection with the cities discharging sewage into the Great Lakes. In 1910 a treaty was promulgated between Great Britain and the United States whereby it was agreed that sewage should not be discharged into boundary waters of the Great Lakes system so that the water would be polluted to the injury of life and property on the other side of the boundary.

The United States Public Health Service investigated conditions at various times and in Hygienic Laboratory Bulletin No. 77 in 1911 drew the following general conclusions:

Sewage pollution of Lake Erie must be controlled. The zone of polluted water should be lessened and not widened. No crude sewage should be discharged into the lake without treatment. Existing faulty sewer systems should be eliminated as rapidly as engineering and economic problems connected with the change can be solved. Inasmuch as the development of these sewer systems has extended over a great number of years, and their existence today represents capital invested, their elimination will be correspondingly slow. In the meantime cities taking their water supplies from the Niagara River or from Lake Erie should

subject them to filtration or disinfection or both, to render those supplies safe for drinking purposes.

The International Joint Commission established under the provisions of the 1910 treaty investigated this subject at length and made recommendations in 1917 substantially as follows:

The Great Lakes beyond their shore waters and their polluted areas at the mouth of rivers which flow into them, except so far as they are affected by vessel pollution, are in a state of almost absolute purity. With the exception of these pure areas, the entire stretch of boundary waters is polluted to an extent which renders the water in its unpurified state unfit for drinking purposes. In addition some are unfit for bathing. The vessel pollution in certain parts of boundary waters existed to an extent which caused substantial injury to health and property. Such vessel pollution results from waste from the vessels and water ballast which is taken in by lake vessels at their ports of departure and emptied at or near their ports of destination. In some cases mill wastes, garbage, offal, carcasses and other refuse matters are discharged into boundary waters.

The Commission felt that it was entirely feasible and practicable and within the boundaries of economy, to prevent or remedy these pollutions by the installation of suitable collecting and treatment works for cities, by the institution of inexpensive methods for the disposal of vessel sewage, adoption of reasonable rules regulating the use of water ballast and the prohibition or restriction of the discharge of industrial and other wastes.

The International Joint Commission recognized, what has been demonstrated through a long period of difficulty with similar problems in England and in Germany, that in order to remedy and to prevent such difficulties some body should be established with ample jurisdiction to regulate and control these situations on a continuous and permanent basis. This recommendation was not adopted.

Interruptions incident to the World War retarded activities, but nevertheless real progress has been made in building intercepting sewers and pumping stations for relieving the pollution of boundary waters.

Lake Michigan is not a boundary water, but Milwaukee and Chicago and their respective suburbs and neighboring communities have done much in approaching the object sought by the requirements discussed above.

Nearly all of the cities on the Great Lakes derive their water supplies from and, of necessity in many cases, discharge their sewage into the Lakes. In some instances, such as perhaps at Detroit and Buffalo, it is possible to obtain waterworks intakes which are not materially influenced by sewer outlets from the same communities, because the sewage is generally carried away without danger of contaminating the water supply by discharging it at points bellow the intakes. At Cleveland, Milwaukee and Toronto, however, it has not been possible to carry the sewage consistently away from the water intakes because, in these cases, they are located in the open Lakes and not in the connecting rivers, as at Detroit and Buffalo. In the case of Lake intakes much progress has been made by separating by long distances the sewer outlets from the intakes and by the gradual installation of sewage treatment devices in order to keep in advance of interfering pollution effects. In addition, filtration of water supplies was begun early at Cleveland and Toronto.

Other Great Lakes cities will probably be called upon, as time goes on, to anticipate similar objectionable situations.

FACILITIES FOR CITIES ON COASTAL AND TIDAL WATERS

Simultaneously with the developments along the Great Lakes there have occurred during the past 20 years substantial installations and improvements for the disposal of sewage of many towns and cities along the seacoast. In each of these instances, popular demand for cleaner bathing beaches, municipal desire for protecting waterworks intakes or shell-fish beds and central administrative guidance have all resulted in a series of improvements, some of the outstanding ones of which are indicated below.

Much of the work of the Metropolitan District around and including Boston, Mass., has been so directed as to provide better sewer outfall arrangements with consequent improvement in the physical appearance of its neighboring ocean waters. Similarly in the Metropolitan New York District, particularly in Long Island Sound, the waters have been protected by treatment works at various places, consisting of fine screens or sedimentation tanks or long outfalls or combinations of several methods. New York Harbor itself has been aided by sedimentation tanks for clarifying the flow of the sewage of the cities in the Passaic Valley and by a number of fine screening plants in the city of New York. Improved disposal arrange-

ments have often been pressed forward in this area through newspaper agitation for the prevention and control of pollution of bathing beaches. Such agitation within the past year, as has already been noted elsewhere herein, has resulted in the closure of many beaches through orders by local and state boards of health.

In Los Angeles much of the activity along sewage disposal lines was the direct resultant of the demand for clean bathing beaches. In this instance fine screens and extensive improvements to sewer outfalls have been and still are being provided. Several Florida cities are likewise confronted with the necessity for sewage treatment, because of similar efforts to maintain in a satisfactory state their recreation facilities.

Mention should likewise be made of the activities of the city of Philadelphia in the installation of sedimentation tanks, and in the construction of intercepting sewers in accordance with a comprehensive plan for sewage treatment for additional areas in order to avoid the pernicious effects of flood tides carrying to its water intake the discharge of its own sewer outlets. Baltimore has had tanks and trickling filters in service for many years to protect shellfish layings in the Chesapeake Bay and to avoid nuisances in its harbor.

Enough has been said in the foregoing paragraphs to indicate that substantial progress has been made in the effort to meet the objections from floating solids, oil, sleek and bacterial discharges from sewage emptying into lakes, oceans or tidal estuaries. It is difficult to assign to any individual activity or administrative undertaking the credit for instituting such measurable progress. It is apparent, however, that the last 20 years have seen an awakening of the public mind in its understanding of the importance of the dangers associated with the indiscriminate discharge of sewage into such bodies of water as are herein discussed. Such public opinion has reflected, of course, the efforts of many administrative municipal, state and federal boards and departments, which in turn have been reflections of a more highly educated and appreciative public attitude. One should not neglect to include in such helpful developers of suitable action those groups of property owners and conservationists who have done much to push forward sewage disposal programs, which frequently would not otherwise have seen the light of day, notwithstanding that in some instances the movements may have been promoted by selfish rather than altruistic motives.

CHAPTER XIII

PROCEDURES FOR OVERCOMING LIMITATIONS OF DILUTION METHOD

SYNOPSIS

1. Ultimate Dilution is Inevitable.—All sewage sooner or later is disposed of by dilution. The limitations of the method should not be over-taxed and each problem should be in accordance with its own individual conditions.

2. Efficient Dispersion of Sewage.—In the diluting water the first essential is to correct the unsatisfactory conditions of mixing practiced in earlier years at many places. These preventive measures involve the use of submerged outfalls suitably located and, in the case of large projects, the use of multiple outlets, so that efficient mixing is promoted by keeping the discharges from individual outlets restricted to relatively small quantities.

3. Storm Overflows.—In the case of combined sewer systems, storm overflows, which occur perhaps from 3 to 5 per cent of the time, require careful consideration.

4. Available Treatments.—Where efficient mixing does not give satisfactory results under local conditions, it is then necessary to provide treatment works appropriate for local conditions. Available methods vary widely in efficiency and cost. The available processes follow:

(*a*) *Fine Screens.*—These will remove coarser solids and particularly those which float on water. Similar results may be accomplished in small tanks provided with suitable scum boards or baffles.

(*b*) *Skimming Tanks.*—Oil and floating matters which will pass through ordinary fine screens may be retained by tanks of sufficient size to allow the oily matters to separate at the surface and from which they may be removed from time to time by skimming or other suitable arrangements.

(*c*) *Sedimentation Tanks.*—Settleable solids which cause banks of sewage sludge to accumulate in watercourses are ordinarily removed best by sedimentation in tanks of suitable size. Where unusually effi-

cient clarification is required or where difficulties are caused by industrial wastes, chemicals may be advantageously used.

(*d*) *Oxidizing Treatment.*—Where a positive oxygen balance cannot otherwise be maintained, it is necessary further to purify the sewage preferably after clarification by preliminary treatment with fine screens or sedimentation tanks, so as to oxidize the non-settleable organic matters. This may be well accomplished by some form of filtration or by the activated sludge process.

(*e*) *Bacterial Removal.*—Objectionable bacteria are removed in the course of the treatment processes above outlined. Fine screens remove a very small percentage, sedimentation removes about as high a percentage of bacteria as it does of total suspended solids and the finishing treatments, such as filtration or the activated sludge process, remove from 80 to 98 per cent of the objectional bacteria, depending upon the method and its application.

(*f*) *Chlorination.*—Where more complete removal of objectionable bacteria is required, it is necessary to chlorinate the sewage after it has been through treatment works, for the purpose of securing some or all of the benefits set forth in preceding paragraphs. Such chlorination does not produce absolutely complete sterilization, but under careful management it can approximate practically such results.

USE AND STATUS OF DILUTION METHOD

Consideration of procedures for dealing with the shortcomings of dilution may properly be prefaced with the statement that the dilution method in many respects requires just as careful, if not more careful, study than purification arrangements. In the case of large streams or other bodies of water, particularly in connection with small communities, this is not true. In the majority of instances, however, experience shows that inadequate dilution ratios, imperfect mixture of sewage with the diluting water, sludge banks, and movements of water polluted by mixture with the sewage toward bathing beaches, waterworks intakes or shellfish layings produce situations requiring careful consideration of factors described at length in the preceding chapters.

In 1904 Fuller found, of an estimated population of 28,000,000 persons in the United States served by sewerage systems about 96 per cent used the dilution method of sewage disposal. In 1915 Metcalf and Eddy estimated that the corresponding figures were 41,800,000 and 84 per cent, respectively.

Of the cities having a population in 1924 of more than 100,000 people (1920 census), the sewage was treated in the case of

about 20 cities having an aggregate population of about 3,350,000. This is 12 per cent of the total population of this group of cities.

Progress toward remedying the shortcomings of the dilution method has been greater than these figures indicate, in that they do not record the fact that many cities during the past few years have investigated means of intercepting their sewage and delivering it later to sewage treatment plants. In other words, real progress with needed preparatory stages has been made at various cities. Without doubt there is a well defined trend towards remedying the shortcomings of the dilution method as earlier practiced, and to use it under conditions which are suitable.

REMEDIAL PROCEDURES

Remedial measures may be classed under two general headings:

(*A*) **Efficient Mixing.**—This means that all of the discharged sewage is promptly mixed with a suitable quantity of diluting water so that adequate ratios of dilution are provided before unsatisfactory results are produced.

(*B*) **Sewage Treatment.**—This deals with the various methods available for eliminating from sewage, before its discharge into diluting water, those objectionable constituents which have been described in preceding chapters and which, if unremoved, cause the objectionable conditions found in many places.

In this chapter we shall detail practice in respect to efficient mixing. The subject of treatment works is dealt with at length in following chapters as it constitutes an essential part of modern sewage disposal practice. Here we shall simply state that it is feasible to purify municipal sewage to practically any degree needed to meet the demands of any local situation. The engineer can design and build works to meet any situation, but it is obvious that the rule of reason must apply to expenditures. On the one hand, the works should be adequate to serve reasonable demands of municipal sanitation. On the other hand, costs of this item of municipal hosekeeping should be in reasonable conformity with numerous other lines of expenditure related to public health and welfare. It is important to consider where each dollar of public expenditure will do the most good.

COMPREHENSIVE PLANS WITH PROGRESSIVE INSTALLATION

It is wise to prepare comprehensive plans for intercepting and treating sewage, based on the needs of a long term of years.

Then works can be actually installed in a progressive way with suitable bugets applied to building on a unit or sectional basis all in conformity with ultimate requirements.

In this way the sewage may be first screened or settled and later filtered or subjected to activated sludge treatment, when needed. As cities grow they will naturally need more treatment facilities and it is sound policy to make the plants parallel such needs. This lessens the initial financial burdens and aids in progressively meeting the increasing need.

INDUSTRIAL WASTES

There are cities and towns where the discharge from municipal sewers contains industrial wastes in quantities far exceeding household wastes. In some situations the added quantities of industrial wastes add serious difficulties to the problem of adequate sewage treatment. As a rule these may be overcome by building suitably selected sewage treatment plants of sufficient capacity and of the types used for non-industrial communities. However, there are cases where the quality or quantity of industrial wastes require, in the interests of economy or efficiency or both, separation at the mills of at least portions of the wastes to be dealt with at their point of origin. No generalizations are necessary here beyond a word of caution that special problems of this sort require thorough going special investigation, as exemplified by the excellent studies of the Sanitary District of Chicago and of the United States Public Health Service. (See Appendix A for Contractual Relations.)

Generally speaking, acids and other chemical wastes which bring about disintegration of sewers and treatment works should be rigidly excluded from public sewer systems. Gas-house wastes are precluded by ordinance from discharge into sewers in some localities. Utilization of such wastes has lessened the complications arising from them, although they should be carefully investigated in every instance.

Phenol wastes add greatly to the difficulty of providing suitable public water supplies in districts where these substances reach bodies of diluting water in objectionable quantities. At Milwaukee it was found that, within reasonable limits, these substances when mixed with the city sewage could be reasonably treated by the activated sludge process. This should not be taken

for granted elsewhere without due investigation. (See Appendix B.)

In closing these introductory comments on remedying the shortcomings of the dilution method it is well to point out that the statutes of many states provide that state health departments assume jurisdiction over sewage disposal. Rules as to sewage disposal practice differ somewhat in different states in this country. The more densely populated eastern states with their comparatively small rivers and with state health organizations of greater age have more stringent requirements than in many of the southern and western states, more sparsely populated and with less comprehensive programs for supervising municipal sanitation in the interest of the public health.

The present requirements as to statute law and some of the outstanding features of the common law as applied to the sewage disposal problem have already been discussed in Chapter II.

SUBMERGED SEWER OUTLETS

Little attention in earlier years was given to the art of arranging sewer outlets so as to avoid nuisance. The earlier custom was to convey the sewage only to the edge of the stream and in frequent instances only to the water line at flood stages. The result was marginal pollution along the banks of the stream, with relatively small benefit derived from the diluting power of the stream away from the bank where the outlet was located.

Along the seacoast and neighboring waterways poorly arranged sewer outlets frequently caused substantial nuisances due to the accumulation of sewage solids on mud flats exposed at times of low tides. Similar occurrences were found on marginal strips of lakes and rivers during periods of low water. In 1888 Hering recommended to the City of New York that sewer outlets be extended from the bulkhead to the pierhead line. A period of nearly 20 years was required for installing pipe extensions for the sewer outlets around Manhattan Island. Even this did not fully meet reasonable requirements owing to the fact that incoming tides pocketed sewage solids in slips where putrefying sludge mud was stirred up by entering boats.

One of the first submerged outlets was put in service at Providence where the effluent of the sewage treatment plant was discharged near the center of the channel of the Providence River,

practically at the bottom where the depth of water is about 40 feet. During the war, harbor line improvements necessitated the cutting of these outlets, and the change in local conditions was very striking. By some the comment was made that the discharge near shore after treating the effluent was apparently less satisfactory than would be the discharge of untreated sewage at the bottom of the main channel. At present (1926) during flood tide, the treated sewage is run into storage tanks, from which it is emptied at ebb tide.

At Cleveland the main lake outfall, put in service in 1905, discharges dry weather flow through a 63-inch riveted steel pipe line turned up at the end to an elevation of about 25 feet below the surface of the water and about one-half mile from shore. A well defined sewage field is noticeable in its vicinity.

At Washington the sewage is discharged through two 60-inch pipes with upturned elbows into the Potomac River in mid-channel in about 30 feet of water. In this tidal stretch of the Potomac River the water is fresh but turbid and there is substantially little evidence of the sewage discharged around the outfall and the shores are clean and entirely free from evidence of the discharge.

In the Boston Harbor the Boston Main Drainage System completed in 1884 discharged the sewage into reservoirs at Moon Island in which it was stored for several hours in order to allow the sewage to be discharged practically at the surface of the water on outgoing tides. This arrangement is still practiced, but the size of the sewage field is such that later outlets in that harbor have all been submerged as will be described later. Storage tanks have been installed at several localities on Long Island Sound and elsewhere.

Two outlets were provided for the discharge of the South Metropolitan Sewer System in the vicinity of Peddock Island, Boston Harbor. The two 60-inch cast-iron pipes, with mouths looking upward, discharge in about 30 feet of water. A sewage field is noticeable there but far less so than at Moon Island.

At Los Angeles the outfall sewer in use for many years terminated in the Pacific Ocean 942 feet from shore. Its submerged end was 6 feet below mean sea level at a place where sea water is about 16 feet deep. The outfall was of 34-inch creosote wood stave pipe terminating in a riveted steel drop pipe 40 inches in

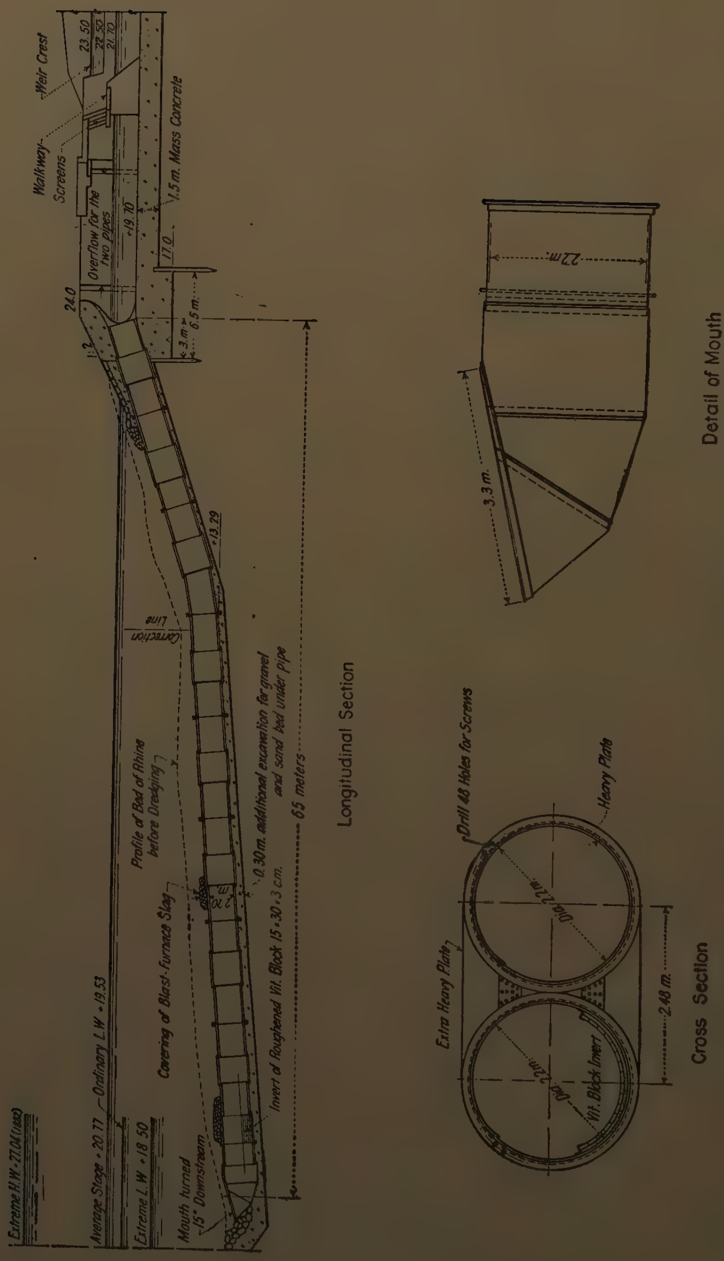


FIG. 8.—Dry weather outlet of Emscher River into Rhine.

diameter. It was submerged on a timber pier built specially for the purpose. This outlet is now used only for emergency purposes.

The new Los Angeles outfall sewer extends as 7-foot concrete pipe for a distance of about one mile into the ocean, where it divides into two 60-inch pipes at 45 degrees from the axis of the main pipe. The southerly branch has a length of 114 feet and the northerly branch of 310 feet. At the ends of the two branches, where the depth is about 56 feet, there are fittings through which the sewage is discharged upward.

In Germany, piping with submerged outlets has been provided for discharging the entire ordinary flow of the Emscher River into the Rhine, which has a much greater volume of flow of purer water. As shown in Fig. 8, two pipes about 86 inches in diameter discharge through ellipitical orifices about 40 feet apart at a depth of about 25 feet below ordinary low water in the Rhine.

MULTIPLE OUTLETS

The City of Toronto was one of the first cities to provide numerous outlets for the discharge of sewage from a submerged outfall pipe, in order to provide prompt dispersion and efficient mixing. After the sewage is passed through settling tanks it discharges into Lake Ontario through a tapered steel pipe extending 3200 feet from shore where the water reaches a maximum depth of 23 feet. The discharge is through 4-inch holes spaced 8 feet apart.

Among the more notable and satisfactory large projects with multiple outlets are those at Boston (Deer Island), and the Passaic Valley works in upper New York Bay.

Boston.—Prior to 1917 the sewage of a part of Boston and outlying municipalities, having a population of about 625,000, was discharged in Boston Harbor a foot or two below low tide through the upturned end of the main outfall sewer. This discharge produced offensive conditions. The sewer was therefore extended 315 feet, carrying it into the channel, and 14 outlets were provided in a length of 119 feet at depths varying from 30 to 50 feet below low tide. These outlets are in the top of the pipe, but discharge horizontally. This provision of deep multiple outlets was stated by F. P. Stearns to have removed substantially all of the previously existing offensive conditions, and to have

mixed the sewage with salt water to such an extent that the sewage could not be detected 300 feet away from the outlet.

Passaic Valley.—The outfall sewer of the Passaic Valley Sewerage Commission, put into service in 1924, is designed to

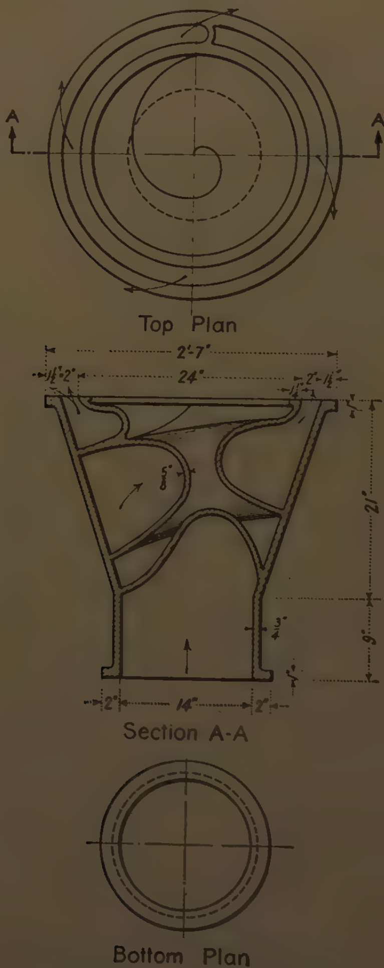


Fig. 9.—Passaic Valley sewer outlet.

serve a population of 1,600,000 and discharges in New York Bay near Robbins Reef Light. Discharge takes place upward through 150 nozzles or diffusers of the type shown in Fig. 9, which are designed to give a whirling and outward motion to the sewage as

it leaves the periphery of the nozzle in a thin ribbon. The area through which the nozzles are distributed comprises about 3 acres, and the tops of the nozzles are 40 feet or more below mean

FIG. 10.—Rochester, N. Y., outfall, under construction.

low water. Dispersion of the sewage in the water of the bay is practically complete.

Figure 10 illustrates the manner in which a submerged out fall is constructed.

CHAPTER XIV

COLLECTING SYSTEM FACTORS

1. Freshness of Sewage.—Since Hering's report in 1882, to the National Board of Health, it has been known that sewage should be brought to the point of disposal as promptly as possible and with minimum opportunity for the decomposition of sewage solids within the collecting system. Because the behavior of treatment plants is so closely related in many instances to factors arising in the collecting system and not the disposal works, a summary of such factors is desirable.

2. Watertightness of Sewers.—This is of more importance from the disposal standpoint than is generally realized. It is not unusual to find that during rainy seasons sewer flows with the separate system are increased from 50 to 100 per cent, due to leaky joints on the street sewers and house connections. In extreme instances, leaky sewers and high ground water levels occur together so that for months at a time flows of sewage in separate systems reach three to four times the quantity of domestic water used. This is a needless waste where the sewage must be pumped and treated in tanks or other arrangements whose capacity is directly related to volume. It is not unheard of to find pumping station and treatment plants over-taxed in capacity before there is a single connection made with the sewer system.

3. Roof Leaders.—These conduct roof water to separate sewers in many cases and add greatly to the burden of sewage disposal facilities. The connection of roof leaders to sanitary sewers should not only be forbidden, but they should actually be detached so far as practicable.

4. Untrapped House Connections.—These are preferable to connections with traps. Trapped connections cause the interior of pipes to be coated with a slimy deposit to which sewage attaches in such a way that decomposition processes with undesirable odors are promoted. There is still some difference of opinion in this regard, but modern practice shows that a free

run from household fixtures direct to the sewer is preferable. Free circulation of air between the street sewer and the open roof terminal is thus secured.

5. Ventilation.—Perforations for manhole covers are unnecessary for providing ventilation, particularly if the house connections are untrapped. At many places it has been found advisable to plug manhole covers to prevent the entrance into the sewer of storm water and the accompanying street wash.

6. Comminution.—Needless comminution of sewage with its effect in lessening the efficiency of sedimentation facilities should be guarded against in hillside communities through suitable use of drop manholes.

7. Traps on Kitchen Connections.—In the case of hotels and institutions traps should be provided so as to lessen the grease and debris reaching the treatment plant. This is particularly important for small residential or institutional systems and was found to be necessary at army camps. Debris and soap not only tend to lessen efficiency of sedimentation, by causing various solid matters to be cemented together so that they will float, but grease also promotes acid fermentation to an undesirable extent in sludge digestion processes.

8. Cesspools.—These have been generally abandoned in America where they existed prior to the introduction of sewerage, but they are still the practice in some European countries. Cesspool overflows are undesirable in that they may bring to the sewers organic matter in an advanced state of decomposition. Moreover the burden of the cost of cleaning cesspools still remains an item which frequently approximates or exceeds the annual interest charges on the assessment for sewers made upon abutting sewered property.

9. Gasoline and Oil Tanks.—Many cities make it unlawful to connect through sanitary sewers the drainage of garages and filling stations. Increasing occurrence of explosions due to gas accumulations in sanitary sewers is the reason for this rule, which calls for a trap of suitable size and arrangement for the interception of gasoline, oils or similar products, which might otherwise do damage to the sewers. From such stations the connections should be to the storm water drains and not to the sanitary sewers, where such a program is feasible.

10. Industrial Wastes.—Discharges of gas-house wastes, acids and other products, which either affect prejudicially the integrity

of the sewer system or make the treatment of the discharge from the public system an inexcusable expense, should be forbidden. This is a question which needs special investigation, since it is a fact in some instances that it is more practicable to allow some wastes to enter municipal sewers and have the municipalities assess a special tax on the producers of the waste, than to treat the waste at the point of origin.

Treatment of some industrial wastes is advisable and necessary at the point of origin, particularly in cases where large volumes of solid matter are formed.

At industrial plants where large volumes of wastes are released at high rates of flow, provision should be made for storage tanks suitably arranged so that they may be discharged over a considerable period of time and thus guard against extraordinary expense for providing peak load capacities for pump stations, treatment plants and connecting pipes and sewers.

11. Stranded Solids.—Smooth interior surfaces of sewers are highly desirable, in that they lessen the lodgment of sewage solids which in some cases decompose and set up undesirable biochemical changes related to odors, which are more difficult to control than to prevent.

Clogging by tree roots is a serious matter in some places. In sewers or house connections they dam up the sewer so as to cause undesirable decomposition products. This item should be dealt with efficiently, in sewer designs and in rules for house connections, so that this complication, when taken in conjunction with leaky sewers, may be avoided by the use of cast-iron or vitrified pipe, tightly jointed, with bituminous compounds or otherwise.

Non-depositing velocities in sewers are desirable, but it is a fact that fairly satisfactory results may be obtained where grades are so flat that at times the liquid will run away and leave the sewage solids stranded on the bottom and sides of the sewer pipe. With vitrified pipe this situation will not give serious complications, providing about 28 inches per second velocity is secured once a day or perhaps several times each week.

12. Sewer Cleaning.—This is an important part of the operation and maintenance of some sewer systems, particularly those on the combined system and where there are interceptors in which the range in flow is great as between the dry weather flow and that which is inducted through the interceptors, in order to lead

to the main outlet the first flushings of the system. In some sewers the long-continued accumulations of sewage solids become objectionable in several ways, and especially because of the odorous decomposition products arising from putrefaction of stranded solids. In large sewer outfalls this is also true. At Baltimore, Paris and some other places, boats of special design are provided in order to promote scouring velocities in the space between the bottom of the boat and the bottom of the sewer.

13. Storm Sewer Inlets.—Leading street water to combined sewers through storm inlets with catchbasins in which to retain the coarse detritus was general practice in earlier days. Modern eductors allow such catchbasins to be cleaned at moderate expense, although during and since the war, cases are not infrequent where such catchbasins have been allowed to fill and remain uncleaned for a long period and perhaps indefinitely. Opinion varies as to the need for such catchbasins. Some of the most experienced sewerage engineers favor their omission and prefer a direct lead of the street wash into the combined sewer. From the standpoint of sewage purification this method has its advantages, although in some cases it may mean the stranding of the solids in the sewer and their consequent cleaning, if decomposition products are to be scrupulously avoided. Such catchbasins provide a trap which is desirable where hydrogen sulphide or other products might otherwise escape, if by chance they be allowed to reach the sewer. On the other hand engineers object to inlets with traps on the basis of mosquito breeding, although it is possible to keep catchbasins oiled to prevent mosquito growth.

14. Flushing.—Where sewage solids become stranded and are not dislodged by suitably high velocities from time to time, it is highly desirable to provide flushing arrangements at the upper end of the sewer lines. Automatic flush tanks are not now installed with the frequency of former years, particularly because of their cost and the expense for attendance to insure proper operation, and partly on account of the cost of the needed water led to the flush tanks in volumes such as to insure a continuous flow.

The more usual practice now is to flush the upper ends of sewer lines with a hose or to put in the upper manhole a flushing gate which when closed will allow the manhole to be filled with water from a hose. Hose flushing is also helpful on some occasions

at points below the end of the line. In some instances, special flushing connections have been made with neighboring streams.

15. Storm Overflows.—In the case of combined systems of sewers much care is required in the design, construction and operation of sewer overflows so as to secure the desired result. In the northern portion of the United States, storm overflows occur for 3 to 5 per cent of the time during ordinary years. The location of the overflow is equally important, as is the interceptor capacity therefrom. A large combined sewer may be laid in a new and sparsely built area with temporary overflow to the local stream bed far from adequate diluting waters, and the existing intercepting connection prove ample to prevent local trouble. But such construction will be ultimately followed by intensive building and population growth which will then require a large intercepting channel extending to a suitable secondary overflow with only the ordinary capacity thence to the point of sewage disposal. These large interceptors may be much reduced in size below that of the storm sewer, but should have capacity to prevent overflow except at very infrequent intervals and only during the most intense storms in cases where the lower valley is a park area. The disposal of these storm water overflows should receive careful consideration. The Ministry of Health of England requires that storm flows, up to three times the volume of the dry weather flow, shall be treated in the main purification works, while special facilities like settling tanks, less complete in their capacity for purification, must be provided to handle flows between three and six times the dry weather flow. English sewage is some three times stronger than ordinary American sewage and in this country treatment plants are seldom designed to provide for more than double the normal dry weather flow which the treatment works are intended to take care of. Special treatment of additional quantities of storm overflows is seldom provided. They are sometimes chlorinated in cases where the flow has a fairly direct relationship to water supply intakes or public bathing beaches.

16. Aeration to Prevent Over-septicization.—Before closing this summary of conditions in collecting systems of sewers, from the standpoint of the behavior of the sewage at treatment plants, it may be well to point out that the anaerobic decomposition of sewage sometimes advances to such a point that, before the sewage reaches the outlet, its biological characteristics are estab-

lished in a way which cannot completely or readily be modified so as to facilitate more satisfactory treatment. Under some circumstances this has led to recommendations for emergency use of air applied through perforated pipes placed in long outfall sewers. Obviously, the purpose has been to stir up stranded solids and to provide atmospheric oxygen so as to maintain biochemical changes on an aerobic rather than an anaerobic basis, as explained in Chapter VI. Some years ago the authors recommended such a step for trunk sewers both at Chicago and for the Passaic Valley project in New Jersey, in neither of which has there been the occasion to install them. These arrangements have been elsewhere considered in connection with the pumping back of activated sludge for some distance in the sewer outfall with a view to making it serve as an aerating chamber and thus constituting a part of a system of activated sludge treatment. None of these arrangements, however, have materialized.

At Bath, England, it has been proposed to introduce air into a long force main, in which owing to its size the period of transit is so long as to promote putrefaction.

Further details on these topics will be found in standard books on sewerage, particularly in Metcalf and Eddy's "American Sewerage Practice."

CHAPTER XV

GRIT CHAMBERS

SYNOPSIS

1. Description.—The term grit chambers is applied to comparatively small chambers, practically enlarged sections of the sewer. They usually precede a treatment process for the separation and retention of sand, cinders and other mineral matters. Catchbasins usually installed at street inlets of combined and storm water drainage systems are of value in retaining street wash, if systematically cleaned. They do not take the place of grit chambers, although they materially reduce the load of the latter.

2. Advantages.—Large quantities of grit or similar mineral matter reaching sedimentation basins have a tendency to form heavy compact sludge which is difficult to remove, unless the slopes of floors and drains are increased considerably above those which would ordinarily be required for sanitary sewage from separate systems. By the use of grit chambers a material portion of the suspended mineral matters in the flow from combined sewers can be removed.

3. Applicability.—Grit chambers are particularly advantageous in combined sewer systems tributary to sewage treatment works, as such systems receive much grit from surface wash during storms and from street flushing. Except ahead of inverted siphons, their use is seldom of advantage in separate sewer systems, as sanitary sewage contains little readily settleable mineral matter. Grit chambers are also of value in protecting pumps from scouring, clogging or abnormal wear, and are useful in bringing about the deposition of mineral matter under favorable conditions for removal before the sewage enters inverted siphons or suction wells of pumping stations.

4. Disadvantages.—If grit chambers are of too great capacity they promote deposition of too much putrefactive organic matters which may cause nuisance. If cleaning arrangements are faulty, or are not properly operated, velocities will increase to above the

depositing point as the chambers become filled with detritus and the entire advantage of the grit chamber will be lost.

5. General Status.—Grit chambers are coming increasingly into favor in America for removing mineral solids in instances where their removal is thus effected more conveniently and cheaply than in other ways.

AMERICAN PRACTICE

Design.—The desirable velocity of flow in grit chambers is about one foot per second, and the period of travel through the chamber should be about 1 minute. If the velocity is increased much above one foot a second, a smaller percentage of the grit will be deposited, and if lower velocities are used, organic matter will be deposited.

Either the cross-section of the basins should be varied to provide the desired velocity with fluctuating rates of sewage flow or several units should be provided in parallel with inlet connection so arranged that only one will be in service during dry weather and additional units will automatically come into operation when the flow exceeds the capacity of the dry weather unit. A separate conduit for the dry weather flow is desirable.

Means should be provided for the economical removal of deposited grit. Bucket elevators and grab buckets traveling along the length of the grit chambers, suction dredge arrangements as at the Philadelphia plant and scrapers are all used in this connection to fit local conditions, but such arrangements should be ample in capacity to remove the grit about as fast as it is deposited under maximum storm and surface wash conditions.

At Cleveland, Ohio, and the Dyckman Street plant in New York City, sloping bottoms, somewhat after the fashion of Imhoff tank partition walls, provide for the settling out of grit into a lower compartment. At the Dyckman Street plant grit is removed continuously by Otterson eductors operated by water pressure.

Grit chambers should be protected by racks with clear openings of from 2 to 5 inches. Underdrains or other methods should be provided for draining off the liquid when the tanks are out of service for cleaning or repair. Drains should discharge into the outlet sewer, or better to the treatment works, as for instance, at Atlanta, where they drain to the trickling filters.

Quantity of Grit.—Information is available in regard to the amount of grit removed per million gallons or per thousand population, but such information is of little value excepting as concerns facilities which must be provided for the disposal of the grit. In any design it is necessary to secure information as to the amount of grit which may be expected during storms under maximum conditions that will tax the apparatus to the greatest extent. The condition and extent of street surfacing, the procedure of sanding streets in slippery weather, the proportion of the sewerage system which admits surface water and other factors influence the problem to such an extent that data collected in any one place have little bearing at others.

Generally the volume of grit varies from 2 to 20 cubic feet per million gallons, depending on local conditions.

At Worcester, in 1924, with 140 miles of combined and surface water sewers, there were removed from the 4121 catch basins, 15,049 cubic yards of material, and from the grit chambers there were removed 0.078 cubic yard of grit per million gallons of sewage.

At Boston, grit chambers on combined sewers have a capacity of 45 seconds and a removal of 0.65 cubic yard per million gallons is indicated. Moon Island records showed a maximum removal of 1600 pounds of detritus per million gallons of sewage.

At the Cleveland grit chambers about 0.075 cubic yard of detritus was removed per million gallons with velocities of about 1 foot per second.

At Washington with 690 miles of sewers, in 1915, about 8200 cubic yards of silt were removed from catchbasins on streets; 29,400 cubic feet of silt were removed from sewers, 71,100 cubic feet from the main grit chamber at the pumping plant and 708,400 pounds were removed by sewage screens. The main grit chamber has a present capacity of 2½ to 5 minutes and a velocity of ⅓ to ⅔ foot per second. It is provided with a gated bypass and is regularly dry-cleaned without nuisance.

In Philadelphia in 1924 with a velocity of 0.85 foot per second in grit chambers the grit removed averaged 2.5 cubic feet per million gallons.

Character of Grit.—Grit should consist principally of wet sand, but will always contain organic solids. At different places the latter have ranged from 10 to 50 per cent, but the higher figure shows the use of objectionably low velocities. Tests by Winslow

and Phelps with Boston sewage showed that grit chamber deposits of about 4800 pounds of wet grit contained about 1300 pounds of water, 570 pounds of clean stone and 2900 pounds of fine detritus which showed a loss of 319 pounds on ignition.

At Worcester, Eddy stated that offensive grit from the grit chambers weighed on an average about 2000 pounds per cubic yard, the dried solids averaged about 65 per cent and the loss on ignition about 23 per cent.

General Application.—Grit chambers are being installed in most sewage treatment projects for large cities having combined sewers. This is generally wise, but it is not wise in dilution projects where the sewers discharge into ample waterways and where banks of sand are not bothersome or may be removed in quantity with dredges more easily and economically than from grit chambers.

At Bridgeport, Conn., and Toledo, Ohio, where the disposal of combined sewage is by dilution in a sufficient quantity of water for present needs, the authors advised the omission of grit chambers in the former case, preceding pumps and fine screens, and in the latter case preceding pumps and skimming tank. While it was understood in these instances that there would undoubtedly be increased wear on pump parts and screen brushes and plates, with somewhat lower efficiency, it was believed that this would be more than compensated for by a reduction in construction and operation costs, as in both cases outfall sewers were some 25 feet below the surface of the soft ground, which would have greatly increased the cost of construction and operation of grit chambers.

REPRESENTATIVE INSTALLATIONS

Early grit chambers were much larger than ordinarily was necessary, and little attention was paid to proper cleaning methods. Since German practice has been followed in this country, mostly through the introduction of Imhoff tanks, grit chambers have been on a more satisfactory basis. The grit chambers at Philadelphia and Syracuse, where special attention was paid to intercepting mineral matters only are notable examples.

Philadelphia.—At Philadelphia an elaborate grit chamber has been constructed at the head of the long inverted siphons which carry the combined sewage flow to the Northeast Sewage

Treatment Works. The location is in a residential district and the entire installation is underground, so that nothing appears above the surface except the ornamental superstructure which is used as an office. The ground around the building has been ornamented with shrubbery.

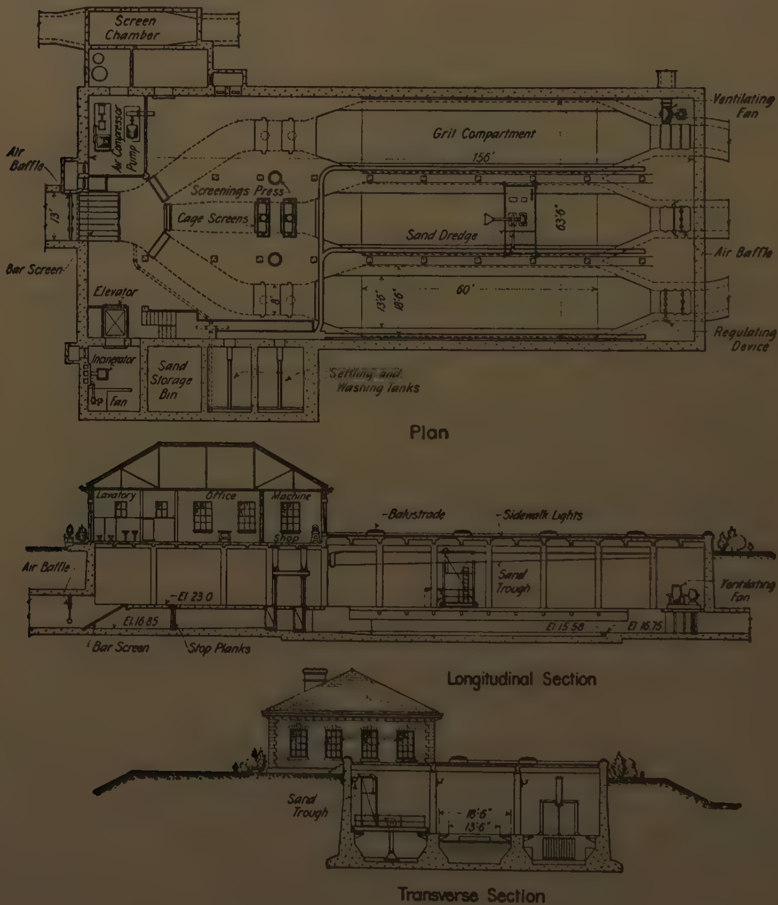


Fig. 11.—Philadelphia grit chamber.

Previous to entering the grit chambers, the sewage passes through racks or bar screens with a clear opening of 4 inches and duplicate cage screens with a clear opening of 1¾ inches. The grit chamber is in three sections of a capacity of 15 million gallons daily and a velocity of 1 foot per second.

The tanks are 60 feet in length, 18½ feet wide on the top and 13½ feet at the bottom, with transition chambers at the inlet and outlet ends 15 feet in length to lower and raise the velocity of flow gradually. At the outlet end there is a specially designed control gate with two leaves shaped to maintain constant velocities irrespective of the depth of flow. The plans provide for removal of grit as fast as formed by a dredge pump having a flexible suction so arranged that it can be placed quickly by a crane in any position or location in the tanks. The discharge of the pump, which is expected to contain about 10 per cent of grit, will be through metal troughs to sand washing bins from which

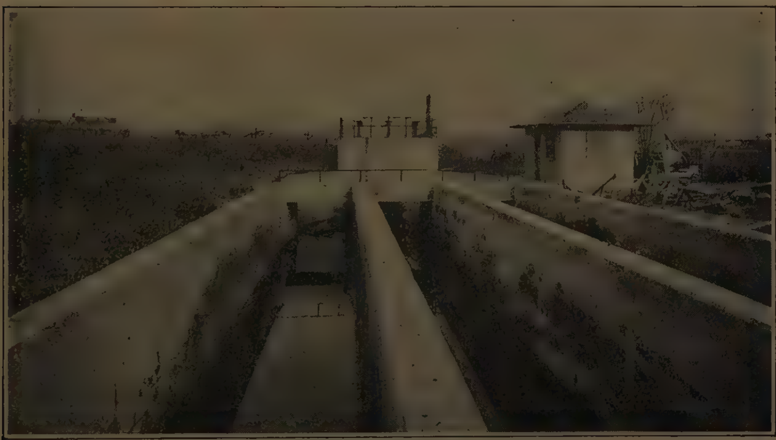


Fig. 12.—Indianapolis grit chamber.

the sewage is piped back to the inlet channel of the grit chamber. In the bottom of the sand washing bins there are manifold pipes and gravel through which air and water can be forced and the detritus washed free of organic matter. The wash water returns to the inlet of the grit chamber and the clean sand is removed by a traveling crane to storage hoppers and then hauled by trucks to the Northeast Disposal Works for use on the sludge drying beds. Pending installation of the suction pump, grit is now removed by a portable Nichols sand ejector and delivered to the sand washing bins.

Figure 11 shows the general arrangement of the plant and the method of removing grit. Arrangements at Indianapolis and Albany are shown in Figs. 12 and 13.

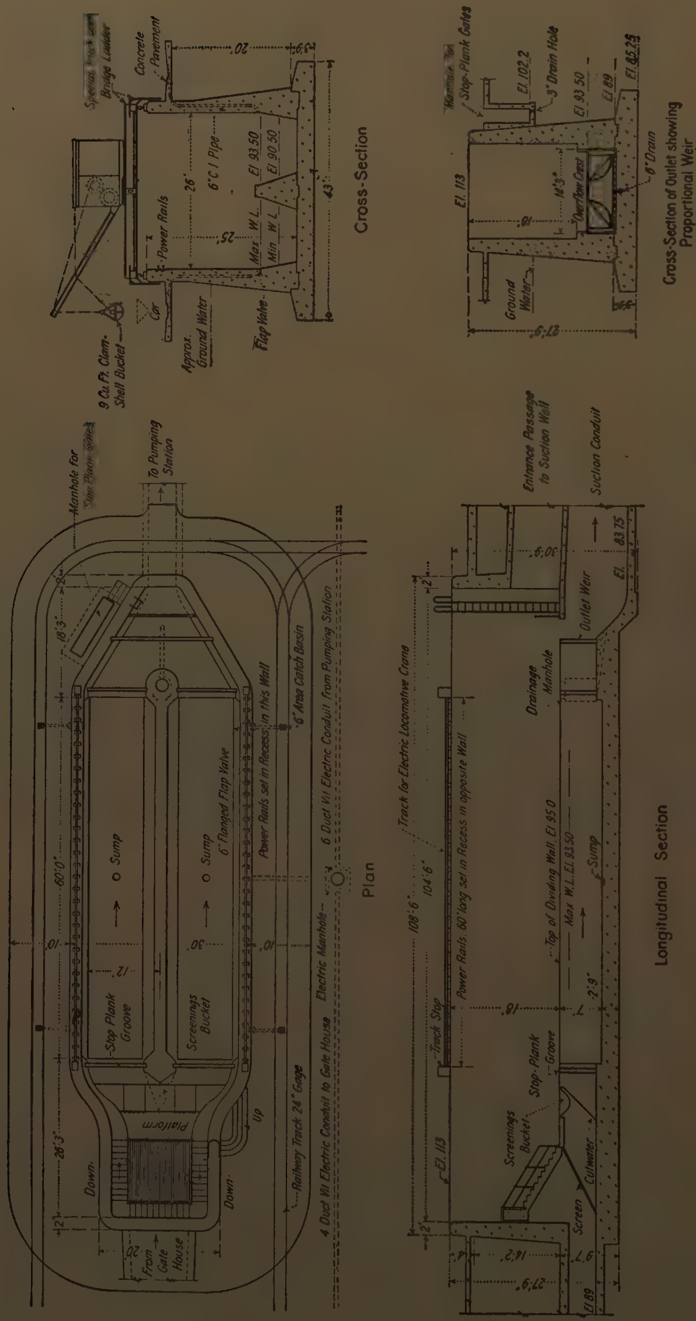


FIG. 13.—Albany grit chamber.

Syracuse, N. Y.—At Syracuse the combined sewage is first passed through grit chambers previous to being screened and settled. These grit chambers were designed for variable sewage flows of from 10 to 55 million gallons daily with a flowing through velocity of 1 foot per second and a detention period of about 40 seconds. The structure is divided into three compartments by two longitudinal walls. These compartments have an inside bottom width of 4 feet and are 40 feet in length. The inlet to each compartment is controlled by an electrically-operated 48- by 54-inch sluice gate having a width of opening equal to the width of the compartment. The superstructure carries a tram rail over the center of each compartment for the cleaning mechanism which consists of an electric hoist and clam-shell bucket. Operation of the equipment is controlled by an attendant within a cab which is mounted on a traveling hoist. The clam-shell bucket has an overall width of 4 feet so that the full width of a compartment is cleaned at each loading of the bucket. As a final operation in cleaning, the bucket is closed, lowered to the bottom and dragged upstream sweeping the chamber clean. Tee rails are embedded in the invert concrete to protect it. The cleaning is done without unwatering, but during the operation the inlet gate is closed so that there is no flow through the compartments. Grit is deposited directly into a truck and is used for surfacing roadways and walks about the plant and for filling low ground in the vicinity. The grit is clean and inoffensive. During the year 1925 the amount of grit removed averaged 0.0923 cubic yard per million gallons of sewage.

One of the interesting features of this plant is the method by which the velocity through the grit chamber is maintained at 1 foot per second irrespective of variations in flow. This is accomplished by varying the speed of the centrifugal pumps which lift the sewage after passing the grit chamber and screens to the settling tanks. The pump control is float operated and functions with the elevation of the sewage level in the grit chamber automatically to change the speed of the pumps.

A variation of 1 inch either above or below the optimum elevations, corresponding to the quantity of the sewage being pumped, causes a change in the pump discharge to correct such condition.

Akron, Ohio.—The Akron skimming-detritus plant, designed by Metcalf and Eddy, will consist of two circular tanks, each 55 feet in diameter by about 13 feet deep, with a small circular sump

extending below the normal bottom of the tank. The sewage after passing through coarse racks will enter each tank through two submerged inlets. About 80 per cent of the flow will pass out through two submerged outlets opposite the inlets. The remaining 20 per cent of the sewage flow will be drawn out from the bottom, together with such deposits as occur. The detention period will be about ¼ hour for the average rate of 33 million gallons daily. For higher rates of flow the detention period will be less.

The tanks will be equipped with revolving arms for skimming grease and floating solids and for pushing this material into a collecting bay whence it will be discharged from drying beds of sand and gravel covered with sawdust. Each tank will also be equipped with revolving plows to push the accumulation of grit and sludge to the central hopper, whence it will flow through a 14-inch pipe line to pumps, which will lift the material, together with about 20 per cent of the sewage flow, to grit chambers. These grit chambers will follow conventional designs, being long narrow channels planned to provide an average velocity of approximately 1 foot per second. Deposition of the heavier inorganic material and more organic solids will pass off with the effluent. The grit chambers will be provided with flight conveyors for cleaning. These conveyors can be operated continuously, if necessary, but probably will require operation for a few hours only each day.

The effluent from the grit chambers will pass through mechanical screens of the Dorrco type. The screened effluent will then be discharged into the conduit leading to the Imhoff tanks, joining the remainder of the sewage flow which will have received partial clarification and removal of floating material in the skimming tanks.

EUROPEAN PRACTICE

From earliest times there has been a growing tendency in Europe to protect siphons, pump wells and treatment arrangements from a needless burden of grit, called detritus in England. English practice relates especially to rectilinear tanks of a much larger relative size than here described for current American practice. Frequently they hold from 30 to 60 minutes' average dry weather flow of sewage and no attention is paid to velocities. The Royal Commission advised for detritus tanks two or more units each equal to $1/100$ of the daily dry weather flow (14.4 min-

utes). This policy relates to the needs of treating wet weather flow with its unusual quantity of suspended solids coming from the street wash. At many, if not most English works, there is little or no difference in the method for final disposal of detritus and of the organic sludge removed without digestion from sedimentation tanks. Excellent mechanical equipment is to be found for removing detritus at most of the large English plants.

The custom of handling the grit separately in chambers as here described came with the advent of septicization or digestion for making organic matters in sludge into inodorous humus before disposal, particularly in two-story tanks. This procedure, originating in Germany, came into favor in America with the two-story tanks.

CHAPTER XVI

SCREENS

SYNOPSIS

1. Racks.—These are fixed bar screens with bar spacing 2 inches or farther apart and are used to prevent injury from large objects to pumping or other sewage handling equipment.

2. Coarse Screens.—As generally designated these have clear spaces between the bars of from ½ to about 2 inches. They may consist of single screens or a series of several screens with different sized openings, and may be either hand or mechanically cleaned.

3. Fine Screens.—These have come rapidly into vogue in the United States during the past 10 years, there now being about 65 separate installations of fine screens for municipal sewage and about 35 for factory wastes. Openings are generally in the form of slots 1/16 inch in width, although slots as narrow as 1/32 inch and as coarse as ⅛ inch are sometimes used. Some have round holes. Fine screens are mechanically cleaned in different ways according to practice of the makers. Prominent types are known as the Riensch-Wurl, Dorrco, Tark and Rex screens. English practice does not deal with fine screens as used in the United States and Germany, but tends to screens of stationary bars and clear openings of perhaps ½ inch, which frequently are cleaned by moving rakes, as is also the case at Toronto, Ont., and Syracuse, N. Y. In Germany, where fine screening had its origin, there are several types which are not described, as it is believed that they do not have particular application to American conditions.

4. Usefulness.—Relatively small screen openings to prevent pump clogging are doubtlessly less needed than in earlier years when valve and impeller openings in pumps were smaller and less capable of passing solid matters than those now available in America and Europe. Six-inch or larger trash pumps have given satisfactory service without screens. It is now feasible to secure pumps of as low a capacity as 250 gallons per minute without serious difficulty from clogging, if protected by bar screens of

¾ inch clear openings or less. Pumps of less capacity require protection by fine screens or chambers to remove large floating or suspended matters. Sewage ejectors may be used instead of pumps as is done in many large office buildings.

5. Efficiency.—Fine screens will remove some 5 to 15 per cent by weight of the total suspended matter in ordinary sewage. Percentage removal varies with the freshness and degree of concentration of the sewage. Dilute sewage of large American cities shows a much smaller percentage removal than in that of many German cities having a more concentrated sewage and less comminution of suspended matter.

6. Applicability.—The function of fine screens in sewage treatment may be either to remove visible objectionable matters which would otherwise appear on the surface of the watercourse into which screened sewage is discharged, or to lessen the suspended matters reaching subsequent stages in a treatment plant. As the sole method of sewage treatment fine screens are limited to locations where nuisance from floating solids is the only factor to be considered, or where lack of space or the reduction of odor nuisance, or other restrictions make it impracticable to employ sedimentation. As an adjunct to other treatment processes, fine screens have been installed at various American cities preliminary to treatment in settling tanks to lessen the quantity of scum; to lessen the amount of sludge and the accumulation of coarse solids on the bottom of aerating tanks, in a number of important activated sludge treatment plants; and subsequent to tank treatment to remove solids which would contribute to the clogging of nozzles of trickling filters.

7. Volume of Screenings.—The amount of solids intercepted by coarse gratings has no significance. Solids intercepted by medium bar screens amount to about 0.6 cubic feet daily per 1000 population and by fine screens, mechanically cleaned, about 1 to 3 cubic feet daily per 1000 population connected.

8. Disposal of Screenings.—Screenings from small plants are ordinarily disposed of by burying or by burning where garbage incinerators are available. At several places screenings are disposed of on neighboring farm lands and plowed under. Some seacoast cities, such as New York, barge the screenings to sea. At a number of plants screenings are pressed and burned under boilers. At New Rochelle, N. Y., screenings are placed in concrete chambers, covered with sand and composted.

KINDS OF SCREENS

For convenience, screening arrangements may be divided more or less arbitrarily into three classes, coarse gratings, medium sized bar screens and fine screens.

Coarse Gratings.—These are bars or posts set with clear openings of from 2 to 6 inches which ordinarily are employed in connection with pumping stations to protect pumps from injury by relatively coarse debris which may enter the sewers through manholes or elsewhere, due to carelessness or maliciousness. They have little influence on the clarification of the sewage, and we will not go into details concerning them.

Medium Sized Bar Screens.—Usually a clear space of from perhaps 0.5 to 2.0 inches identifies this kind. They are in quite general use in this country, arranged in various combinations. Frequently two sets of screens are used in addition to coarse gratings.

Screens, have been installed at sewage pumping stations to intercept sticks, rags or other large floating solids. Centrifugal pumps, 6 inches in diameter or larger, are seldom bothered by strictly sewage matters that are ordinarily removed by screens. In fact, with trash pumps of this size or larger experience shows screens to be unnecessary. With small centrifugal pumps, having small waterways, clogging may be a serious matter. Although it is becoming customary to use specially designed pumps with relatively large waterways, screens with openings not larger than ¾ inch have been commonly provided. The labor of cleaning screens with suitable disposal of screenings is considerable, so that other procedures are sometimes adopted. One is to store the sewage in receiving tanks of such size as to permit the intermittent use of fairly large pumps, although the cost of increasing the size of force mains and of necessary storage must be considered in such cases.

Compressed air ejectors are used in preference to pumps for lifting sewage to small heights when the volume is small, say 100 gallons per minute, on account of freedom from clogging. They are rather wasteful of power, as the cost of operating air ejectors is greater than that of centrifugal pumps. Their general use in office buildings for lifting sewage from sub-basements to street sewers, and for other purposes, is explained by this freedom from clogging and the opinion that it is cheaper so to waste power

than to go to the expense of efficient screening and of getting rid of the screenings.

The size of openings in screens in front of reciprocating pumps depends upon the type and size of the valve used in the water cylinder. Solid matters lodging under valves cause them to remain "unseated," and sewage to a certain extent is forced back to the suction pipe, and power and capacity are wasted as a result of this "slip."

Medium sized bar screens in this country may be divided into three general types, hand cleaned stationary bar screens, mechanically cleaned stationary bar screens and cage screens.

Hand Cleaned Screens.—For small plants where coarse screening only is required, hand cleaned stationary screens are almost universally used. They are ordinarily made of racks in series, usually two, but sometimes three, with the screens having wide openings placed upstream. As a rule, openings are from 1¼ to 1½ inch for the first set of screens, and ¾ inch for the rear screens. They are usually made of steel bars rodded together in such a manner that the rods will not interfere with raking, and inclined so as to be more easily cleaned. The screen area depends on the length of time between cleanings, the freshness of the sewage, and the amount of sewage. Ordinarily for domestic sewage an allowance of 20 square feet per million gallons is satisfactory where screens are raked three times during the day and left clean at night.

While at some recent large pumping plants mechanically cleaned screens are used, yet at older plants there are hand-raked bar screens, as, for instance, at Columbus, Ohio, where three sets of screens are used in series, the smallest having a clearance of 0.5 inch between bars and the intermediate set 1 inch.

Mechanically Cleaned Stationary Screens.—This type of screen is not used to any great extent in this country, although quite common in England. A recent installation at Syracuse is worthy of note. It is placed between the grit chambers and the settling tanks and is built of vertical steel bars spaced ½ inch in the clear. The solids retained by the screens are removed mechanically by rakes, chain operated, the teeth of which pass upward through the screen openings, lifting the screenings to hoppers near the top of the screens, these hoppers discharging the screenings into steel cans. The rakes pass over the entire screen surface about twice every minute.

Cage Screens.—At many of the large sewage pumping stations and some treatment works cage screens are used. These screens are essentially racks inclosed on three sides and placed in the line of the sewage flow, ordinarily two in series, and so arranged as to be lifted from the sewer channel to a floor above, where the screenings are removed. With two screens in series, this allows

FIG. 14.—Toledo, Ohio, cage screen.

one screen to be in place while the other is being cleaned. A recent installation of this kind is that at Toledo, Ohio, where each of the three channels leading to the pump suction wells is provided with two screens of this type. The screens are box or cage type, built up of structural shapes with perforated bottom plates or aprons, 8 feet wide, the width of the channel, and 2 feet 4 inches long, in the direction of the sewage flow. The vertical screen bars, 9 feet in length, of ½-inch galvanized wrought-iron

pipe, are arranged in two staggered rows across the back, with one single row along each short side of the cage. The spacing of the bars is 2½ inches, center to center, in all cases.

The screens are counterweighted and are raised to the floor above by electric hoists. The open-front, box type of construction, with perforated bottom plates, collects the screenings within the screen, and when the cage is raised to somewhat above the cleaning floor, they are easily raked into wheel-barrows. The general arrangement of the Toledo screen installation is shown in Fig. 14.

This type of screen is used in many large plants, that in the pumping station of the South District of the Metropolitan Sewerage Works at Boston, Mass., being one of the first. One of the largest screen outfits of this type is that for the Passaic Valley sewer which handles daily about 100 million gallons of sewage and has an ultimate capacity of 300 million gallons daily.

Fine Screens

Fine screens will be considered here as including only such screening devices as provide for openings, either slots or mesh, of ⅛ inch or less in smaller dimension and with mechanical arrangements for cleaning.

Hand cleaned screens with openings less than ½ inch have little practical significance. At Washington, Pa., and at New Rochelle, N. Y., ¼-inch screens have been fairly successful, but ordinarily such screens clog so rapidly that the tendency is to bypass them so that the actual efficiency is less than would be the case if coarser screens were used.

While even very fine screens do not remove organic matter or bacteria to as great an extent as would sedimentation, yet where nuisance to sight, such as at bathing beaches, is the main object, they are perhaps more satisfactory than tanks, in that they ordinarily remove all suspended solids greater in size in one dimension than the openings in the screen, usually about 1/16 inch.

Types of screens used in Europe for several years have not been installed in this country to any great extent other than the Riensch-Wurl and the Hamburg (endless chain belt) types. Here the screens now most used are the Riensch-Wurl, Dorrco, Tark and Rex. These screens all have distinctive features and as they are typical of all screens manufactured by various concerns in this country, they will be described herein.

Disc Screens.—The Riensch-Wurl type of screen is the only disc screen well known in this country. It has been promoted for the most part by the Sanitation Corporation whose latest product is now known as the Sanitation Disc Screen. As many of the original patents of this screen have expired other manufacturers are now making screens similar to the early type of Riensch-Wurl screen, that in the twenty-sixth ward, Brooklyn, being perhaps the most important example. This type has been installed in a large number of places and has proved successful, both from an efficiency standpoint in removing grosser suspended solids and, from a mechanical standpoint, in that they have worked successfully for long periods at small operating cost and without extensive repairs.

The first Riensch-Wurl screen was installed in this country in 1915, at Daytona, Fla., on the advice of the authors for the protection of bathing beaches, in connection with chlorination. This is still in successful operation and giving satisfactory service.

In New York City several types of mechanically cleaned screens have been installed, principally to remove floating sewage solids. The Riensch-Wurl screens installed in New York City are summarized in Table 41.

Table 41.—Riensch-Wurl Screens in New York City

Plant	Units	Capacity each m.g.d.	Size, feet	Opening, inch	Cost of plant, dollars
Manhattan					
Dyckman St.	2	7.5	14	$\frac{1}{16}$–$\frac{3}{64}$	73,000
Brooklyn					
Twenty-sixth Ward	2	8	14	$\frac{1}{16}$	558,726
	2	20‡	26	$\frac{1}{16}$	
Queens					
North Beach	2	8	14	$\frac{3}{64}$	
Jamaica	2	40	26	$\frac{3}{64}$	1,047,000*†
Hammels	2	30	22	$\frac{3}{64}$	700,000*†

* Including chlorination.
† Including pumps.
‡ This could be doubled by increasing the rate of revolutions.

The plants in Queens Borough represent post-war prices.

There is little difference in the installations of Riensch-Wurl screens, other than in the openings in the screen plate and the

method of disposing of the solids removed. The latter has to do with the question of their being deposited directly into cans for removal by trucks or being blown from collecting hoppers into chambers from which they can be removed by trucks or be composted.

The Dyckman Street plant on the Hudson River frontage in upper New York City has been in successful operation since October, 1918, and is typical of practically all Riensch-Wurl installations in this country.

Dyckman Street Plant.—The plant receives the combined sewage from an area of about 315 acres, mostly residential and about 30 per cent built up. The present dry weather flow is approximately 7 million gallons daily.

After passing through a grit chamber the sewage is delivered to either one of two 14-foot Riensch-Wurl screens with a nominal capacity of 7.5 million gallons daily each. Each screen consists of a circular, bronze disc plate, slotted with openings $\frac{3}{64}$ by 2 inches on one screen and $\frac{1}{16}$ by 2 inches in the other. Above the disc plate and fastened to it is the cone plate resting on the circular disc and securely fastened to it. The cone plate at this plant has no openings, but in some installations it is also perforated in the same manner as the disc plate. Both plates have a common axis of revolution, the inclination of which is 20 degrees from the vertical. In other plants this inclination ranges from 10 to 25 degrees from the vertical. This part of the apparatus, which may be termed the screen proper, is placed in a circular chamber in the line of the sewage flow so that the sewage is discharged onto the top of the lower part of the disc and around the cone and passes through the slots of the screen, which is kept constantly turning on its axis.

At nominal working capacity the sewage on the screen covers approximately the lower half of the plate. Under maximum conditions the plate and cone may be submerged to the point where the brushes would just reach the level of the sewage. As the screen revolves, the solids retained on the surface are brought above the water level and as they approach the high elevation of the screen, they are removed by revolving brushes which are carried around in a circular path by a spider, whose axis is located just ovtside of the highest part of the circumference of the screen disc. The spider revolves in a direction opposite to the direction of the screen and the brushes themselves revolve on their respec-

tive axes in a direction contrary to the screen direction, so that the solids are carried before the brushes into an inclined trough from which they are brushed through an opening into cans.

A later method of handling the screenings is to have the screenings deposited directly into the hoppers of air ejectors from which they may be blown by compressed air to trucks or other receptacles. Where the screen cones are perforated, they have separate brushes which remove the screenings from the cone to the horizontal screening disc from which they are removed with the other screenings.

FIG. 15.—Riensch-Wurl screen at Rochester (Irondequoit) sewage works.

These screens require little attention other than oiling the machinery and the daily cleaning of grease from the slots by brushing with kerosene.

The Riensch-Wurl screen installation at Rochester, N. Y., is one of the oldest plants in this country. The screen installation there is shown in Fig. 15.

Drum Screens.—The first drum screens used in this country were the Weand screens, the first installation of which was at Reading, Pa., to prevent floating solids reaching a septic tank. This type was also installed at Baltimore, Md., Atlanta, Ga., and Brockton, Mass., but in recent installations it has been

superseded by drum screens of more modern arrangements to be described later.

Dorrco Screens.—The Dorrco screen, manufactured and installed by the Dorr Company of New York City, has come into considerable use within the last few years. It is essentially different from other drum screens as there is no cleaning of the screen by brushes or other apparatus. The sewage passes from the outside of the screen to the inside and out through one end. The screen revolves at such a rate as to raise the level of the sewage inside of the screen, on the side furthest from the inlet, some 2 to 6 inches above the level of the sewage on the outside; and this automatically washes from the screen the particles of suspended matter that cling to the outside, leaving a clean surface to be immersed in the incoming sewage. The solids are removed from the screen pit by an elevator having perforated buckets which run on an endless chain and continually raise the solids from the pit beneath the screens to cans or to an ejector for final disposal. The screens are made up of plates with 2-inch long slots and of a width desired, but not less than $\frac{1}{16}$ inch, for handling domestic sewage. For industrial wastes of a fibrous nature plates with round holes have been preferred by some.

Los Angeles Plants.—The largest installations of this type of screen are the two plants at Hyperion, Los Angeles. The sewage at these plants on the ocean front is carried from the city through an outfall sewer approximately 15.4 miles long. At the plant the sewage is divided into two portions for treatment. The South Hyperion plant handles a maximum of 80 and the North Hyperion plant a maximum of 150 million gallons a day. The South Hyperion plant at present comprises eight Dorrco screen units, each unit consisting of a screen drum 8 feet in diameter by 8 feet long, covered with manganese bronze plates $\frac{3}{16}$ inch thick, with milled slots $\frac{1}{16}$ inch in width by 2 inches long. Each screen is operated by a direct connected individual electric motor, connected to the shaft of the screen drum by means of worm gear speed reduction, and is controlled by a separate starting switch. The solids rejected by the screens settle into pits, one of which is connected to each screen unit, and are removed therefrom by means of a slow-speed elevator equipped with a number of perforated brass buckets which ascend slowly so that a substantial amount of time is provided from the moment that the buckets leave the water in the screenings' pit, until they discharge their

contents at the top of the elevator and allow the extraneous water to be drained from the screenings. When the buckets reach the top of the elevator, the contents are dumped into a hopper and into a pneumatic ejector.

One ejector pot is situated under, and directly connected to, each elevator. Periodically, when the ejectors are filled, which is observed by the operator in charge, compressed air is admitted at a conveniently located control panel, and the contents of the ejectors are forced out through a pipe having a horizontal length

FIG. 16.—Dorrco screens at Los Angeles, Cal.

of 800 feet and a vertical rise of 80 feet, to a location on top of the adjacent sand dunes where the screenings are covered with sand. The screenings' elevators are driven by individual electric drive units with individual starting switches, so that they can be operated independently of the screens and independently of each other.

No sewage or screenings can be seen, as all channels in which sewage flows are covered, as are the screenings' pits. The elevators are entirely encased in non-corrosive metal housing, with direct metal connections to the hoppers of the pneumatic ejectors.

The North Hyperion plant has five 12- by 14-feet diameter screens with a total capacity of 50 million gallons per day. It is similar in construction to the South Hyperion plant.

During 1925 the screenings averaged 16 cubic feet per million gallons and the average cost of maintenance and operation for the same period was $1.26 per million gallons.

Figure 16 shows the battery of five 14 feet diameter Dorrco screens installed at the North Hyperion plant with the tops of the screenings ejector housing showing in the rear.

Figure 17 shows the eight ejector pots of the South Hyperion plant and indicates the manner of discharging the screenings from

Fig. 17.—Ejectors for screenings from Dorrco screens at Los Angeles, Cal.

the bucket elevators into the hoppers. When considering these two views together, it may be seen that there is no sewage or sewage matter visible to the eye during the entire operation.

An interesting plant of this type has been recently completed at New Rochelle, N. Y., with two 10 million gallon units similar to those just described except as to the method of taking care of the screenings, which is described under Disposal of Screenings. The New Rochelle screen is shown in section in Fig. 18.

Tark or Link Belt Screens.—These are drum screens revolving on a center shaft, the sewage passing from the outside to the inside of the screen. Cleaning is accomplished by brushes passing longitudinally along the center top of the screen. The

first screen of this kind was constructed at Pleasantville, N. J. There is also a small installation at Keansburg, N. J., and a plant at Milwaukee rated at about 250 million gallons daily capacity, with 12-inch head. This plant was put in service in June, 1925, and is described in the Ninth Annual Report of the Milwaukee Sewerage Commission.

The two-story screen house is 100 feet long by 68 feet wide, and 42 feet high, inside. The lower story contains the screens and the upper a complete laboratory and offices for the executives of the plant.

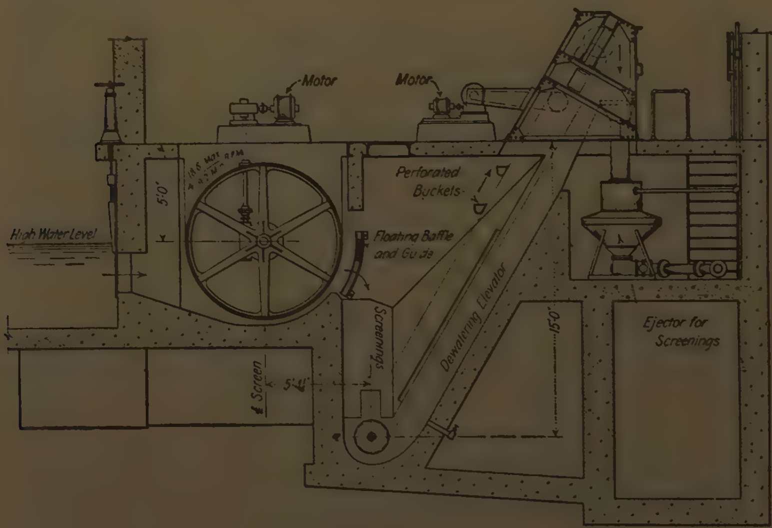


FIG. 18.—Dorrco screens at New Rochelle, N. Y.

There are eight revolving drum screens installed in two batteries of four each, each screen operating independently in its own pit, the flow being controlled by a sluice gate operated by an electric motor. Each drum is 8 feet in diameter by 8 feet long and is covered with manganese bronze plates $\frac{3}{16}$ inch thick, having 27.5 per cent of their surface slotted with openings $\frac{3}{32}$-inch wide by 2 inches long. Each of these screens is independently operated by a 5 horsepower variable speed motor and James speed reducing gear, which turns the drum at a peripheral speed of from 8 to 12 feet per minute. The brush carriage contains eight brushes which pass over the surface of the screen parallel with its axis, at the rate of 60 feet per minute when

the peripheral speed of the screen is 11 feet per minute. The speed of the brushes and drum is synchronized. The apparatus is provided with an automatic device for spraying the brushes with kerosene or other suitable liquid to cut the grease from the screens.

The total capacity of each screen when operating at 11 feet speed, and under an 8-inch loss of head, is 18,720,000 gallons of sewage per day, containing from 225 to 250 parts per million of suspended solids

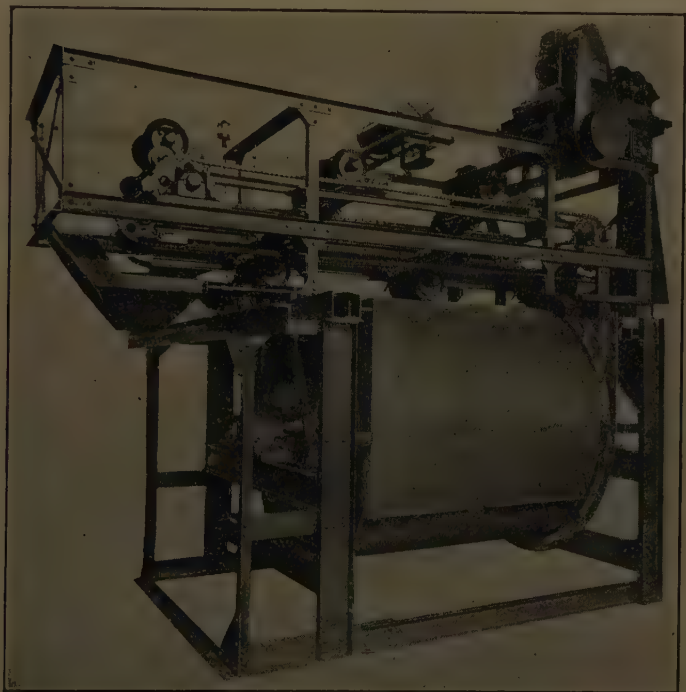


Fig. 19.—Tark type—Link Belt screen.

The screenings are brushed upon a Sandvik steel belt 12 inches wide, one belt being provided for each four screens. This belt delivers the screenings to a pneumatic ejector which discharges through an 8-inch pipe to a bunker located in the filter house.

Figure 19 shows diagrammatically the principal features of the Link Belt type.

Rex Screens.—This type consists essentially of sections of screen fastened to an endless chain placed in a chamber in the

sewage channel so that the sewage passes through the screens which are continually lifted from the sewage and cleaned by brushes, water jets or compressed air, the screenings being dis-

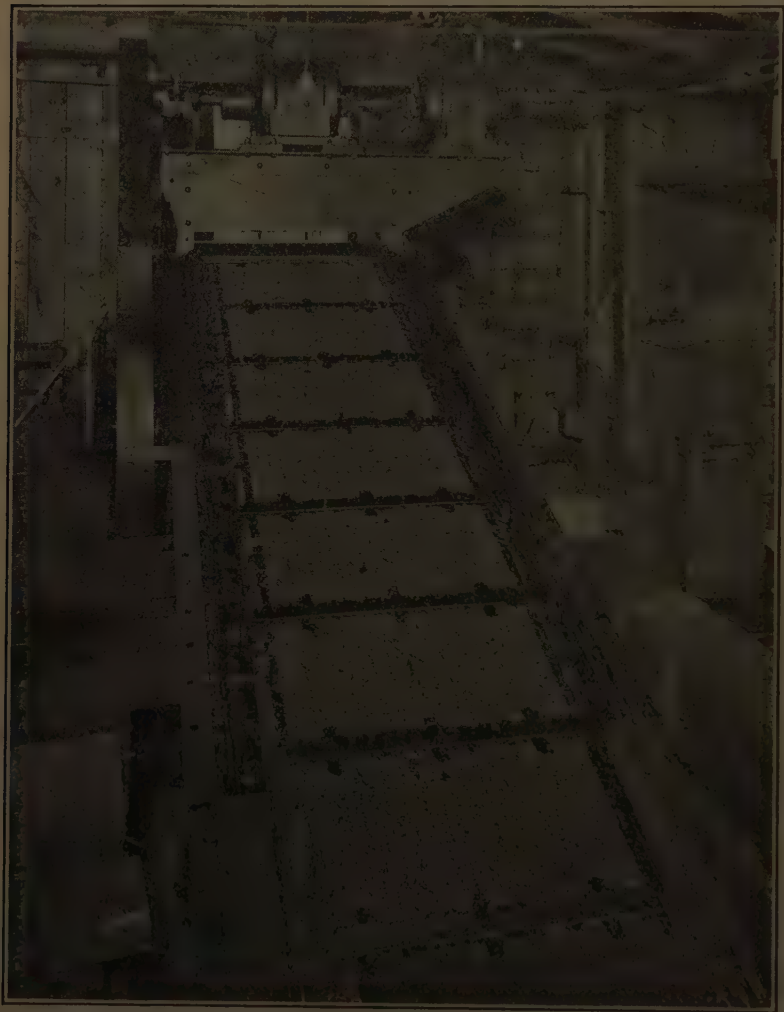


FIG. 20.—Rex screen, Chain Belt Company.

charged into a perforated refuse basket from which they can be removed as desired (see Fig. 20).

These screens have been used for some time for industrial purposes, but have not yet been used to any great extent for

sewage. There is, however, a large plant in New York City which has operated successfully since its installation, and is very well thought of by observers. A description of this Canal Street plant follows.

Canal Street, New York City, Plant.—This consists of three Rex chain belt screens, each of a capacity of 40 million gallons daily. The plant also includes a bar screen 4 by 4 feet wide with 6-inch clear openings between bars for the removal of rubbish, an 18-inch centrifugal pump with a capacity of 8000 gallons per minute, two 24-inch centrifugal pumps with a capacity of 14,000 gallons per minute each, and 6 Wallace & Tiernan automatic chlorine dosing devices. There is no grit chamber and considerable trouble has been experienced from ashes dumped into the sewerage system.

The screen pits are 7.87 feet wide, 43.0 feet long, and 9.0 feet deep, except at one end, which is about 6.0 feet deeper. The screens are composed of perforated plates 1.5 by 6.0 feet attached to chain belts. Each belt is carried on two rollers 3.0 feet in diameter, one at each end, and on a number of smaller rollers along the edge on each side which are supported on rails on the sides of the screen pit. The length of the belt is 102 feet and the distance between centers of the large rollers, 46.5 feet. One of the large rollers is located in the lower part of the screen pit and the other rests on the main floor just outside of the high end of the pit. The screen has an inclination of 20 degrees from the horizontal, and is about half submerged during maximum flow of sewage. The perforations in the plates are similar to those in the Riensch-Wurl screens and are $\frac{1}{16}$ by 2 inches.

Screenings are removed by revolving brushes from the under part of the screen just after the plates turn over the upper roller on the main floor. There are two sets of brushes; the first set just touches the plates and removes the coarser parts of the screenings, and the second set bears with greater pressure against the plates and completely removes the parts of the screenings left by the first set of brushes. The screenings fall from the brushes into hoppers and are discharged from these hoppers by air ejectors into a storage hopper having a capacity of 5 cubic yards. The storage hopper discharges into a smaller hopper of 1 cubic yard capacity, from which the screenings are lifted by compressed air to above the street level where they are discharged into trucks.

The entire plant is under the surface of the ground except for a small building, 15 by 8 feet, through which the compressed air pipes comes from the plant beneath the surface. The drainage area tributary to this plant is about 382 acres, the sewage from which is about 60 per cent residential and 40 per cent industrial. The power consumption is about 1200 kilowatts per 24 hours. The compressor plant is operated by a 50-horsepower motor.

QUANTITY OF SUSPENDED MATTER REMOVED BY SCREENS

No precise general statement can be made as to the amount of solids removed from sewage by screens, which vary much in size of opening and other details. The strength of sewage, the distance it has to travel in the sewers and the age are all governing factors. Much depends also on the frequency with which screens are cleaned and the care taken in removing retained solids as compared with the pushing through the screen intentionally of solids after they have been retained by bar screens. A few examples, however, will show accomplishments in practice.

Coarse Gratings.—Screens of this type remove only large solids such as pieces of wood, rags, etc. Such removal has no significance in sewage purification but is an operating convenience.

Medium Sized Bar Screens.—The bar screen at the old Plainfield plant had a clear opening of 0.5 inch. The screen area was about 2.3 square feet per 1000 population and it was cleaned ten to twelve times in 24 hours. The amount of screenings was 5.7 cubic feet per million gallons weighing 46 pounds per cubic foot with about 84 per cent of water. After draining they weighed about 35 pounds per cubic foot.

At Baltimore, bar screens with 7/8-inch clear openings remove about 3.75 cubic feet of screenings per million gallons.

The Toledo, Ohio, cage screens remove about 2/3 cubic foot per million gallons, the screens being cleaned about once in 24 hours. The contributing population is about 230,000 and the sewage flow about 20 million gallons daily.

Bar screens with 0.5 to 0.75-inch openings show a removal ranging from ½ to 10 cubic feet per million gallons of sewage. The majority of results seem to fall within a range of from 4 to 8 cubic feet per million gallons.

Fine Screens.—The Weand screen at Reading removed about 30 to 35 cubic feet of wet screenings per million gallon of sewages.

At Brockton the same type of screen, but with a stronger sewage, removed about 50 cúbic feet of screenings per million gallons.

At the Bridgeport plant the screens remove about 20 cubic feet per million gallons of sewage which has not passed through a grit chamber.

A test of the Dorrco screen at New Britain showed that there was a removal of suspended solids of 21.3 per cent of the original, equaling about 30 cubic feet per million gallons daily, of a specific gravity of 1.08 and a moisture content of 81 per cent. The dry screenings amounted to about 380 pounds per million gallons. The screen plate had 1⁄16 by ½-inch slots.

The Tark screens at Milwaukee remove from practically nothing to 3536 pounds of 86 per cent moisture screenings per million gallons with an average of about 515 pounds.

The Riensch-Wurl screen at the Plainfield plant was installed to decrease the amount of floating solids in Imhoff tanks. The superintendent, Downes, states that the cost of removing the solids is about equal to what the cost would be for taking care of it in the Imhoff tanks, but that the plant is more workable and the nature of the labor less objectionable with the screens. The efficiency of the screens in 1925 is shown in Table 42.

Table 42.—Results from Fine Screens
(Plainfield, N. J.)

Average sewage flow, million gallons daily	3.10
Number of house connections	8612
Suspended solids, parts per million—screen effluent	214
Screenings, cubic feet per million gallons (89 per cent moisture)	15.8
Screenings, cubic feet per day for 1000 population	1.12
Screenings, parts per million (dry basis)	13

The removal of suspended matters, by comparing the determinations of them in crude and screened sewages, frequently shows unexplainable discrepancies due to difficulties of sampling. A suitable procedure is to add to the suspended solids in the screened sewage the weight of the dry screenings, expressed as parts per million, and thus obtain the total suspended matter in the crude sewage. From these data the per cent removal represented by the screenings can be computed.

A test of the Riensch-Wurl screens installed at Dyckman Street showed average results, weighted in proportion to the flow during the periods of tests, as summarized in Table 43.

TABLE 43.—PERFORMANCE OF RIENSCH-WURL SCREENS, DYCKMAN SREET, NEW YORK CITY

Screen	No. 1		No. 2	
Diameter, feet	14		14	
Width of slots, inch	$\frac{3}{64}$		$\frac{1}{16}$	
Day or night sewage	Day	Night	Day	Night
Crude sewage, results in parts per million				
Suspended solids	175	48	151	55
Volatile	130	44	112	45
Ash	45	4	39	10
Settleable solids	133	48	93	55
Volatile	94	44	62	45
Ash	39	4	31	10
Screened sewage				
Suspended solids	139	21	129	46
Volatile	99	21	92	36
Ash	40	0	37	10
Settleable solids	97	21	71	46
Volatile	63	21	42	36
Ash	34	0	29	10
Screenings				
Suspended solids removed, parts per million	36	27	22	9
Moisture, per cent	78	78	82	83
Dry material, per cent	22	22	18	17
Volatile (dry basis), per cent	88	84	91	91
Ash (dry basis), per cent	12	16	9	9
Volume, cubic feet per million gallons	27.1	9.5	18.4	9.2
Weight, pounds per million gallons	1449	447	1040	447
Weight, pounds per cubic feet	53.4	47.0	56.5	48.6
Efficiency of removal				
Suspended solids, per cent	20.6	56.2	14.6	16.4
Settleable solids, per cent	27.1	56.2	23.7	16.4

In general, fine screens of the type described will remove from 1 to 3 cubic feet of wet screenings per 1000 inhabitants daily, including practically all solids greater in size in one dimension

than $\frac{1}{16}$ inch, the usual opening in fine screens. The removal of suspended matter ordinarily ranges from 5 to 15 per cent.

DISPOSAL OF SCREENINGS

The majority of small plants dispose of screenings by burying and, where land is available, this is probably the most satisfactory method.

Where screens are installed simply to protect pumps, it is possible with an ejector to bypass the screenings around the pumps and mingle them with the sewage after pumping as was done at the General Electric Company's plant at Schenectady, N. Y.

If high-temperature incinerators are available, screenings after draining or pressing can be readily disposed of without nuisance by burning.

In larger plants composting, as installed at New Rochelle, N. Y., seems to be a satisfactory method of disposal. This plant handles an average daily flow of about 5 million gallons and the screens are of the Dorrco type with ejector pots into which the screenings are delivered and from which they are blown by compressed air into the compost building. This compost building has 8 separate units, 15 by 14 by 11 feet in size and the piping is so arranged that the screenings can be delivered to any of them. It is expected that there is sufficient capacity in this structure to store the screenings for about 1 year before removal. It is intended to cover the screenings with from 6 to 8 inches of sand or earth as often as necessary to prevent odors and the breeding of flies. After the screenings have thoroughly decomposed they will be removed by an electric crane and grab bucket to trucks and used as lawn dressing or filling.

This compost plant at New Rochelle has been in service since May, 1926, and experience shows that the wet screenings digest readily. The appearance of the units in use resembles the gas vents of two story tanks and it is important that the surface of the fermenting material be covered frequently with sand or soil. This will keep the odors under control, but it may be helpful to use lime at times.

Fine screenings at Rochester are carried to a dump and covered with the mineral matter taken from the grit chamber.

At Plainfield screenings are spread upon neighboring farm lands and plowed under at intervals.

At Los Angeles they are forced by ejectors through a pipe discharging them onto the neighboring sand dunes.

At New York City they are carried on a barge to sea and dumped with the garbage.

For small installations the best method of disposal is burial. For installations of large capacity either burning or composting seems satisfactory. For large inland plants, composting is the most economical method of disposal and is entirely free from nuisance. Where sea disposal is available for large plants, particularly in the congested district like New York City, that is the best method of final disposal.

CHAPTER XVII

SKIMMING TANKS

SYNOPSIS

1. Description.—Skimming tanks provide by flotation for the collection and removal of oil, grease, wood and other floating matter.

2. Advantages.—Skimming tanks are useful in connection with municipal sewerage systems where disposal by dilution is used to prevent the appearance of sleek or floating matters on the surface of the water, and at industrial plants to limit the discharge into public sewers or into waterways of grease, oils or other floating wastes. Oily materials have a detrimental effect on aeration both in water courses and aerating tanks. At some places skimming tanks are helpful as preliminary to activated sludge or other treatment processes.

3. Present Status.—They are becoming more and more important on municipal sewerage systems with the increased use of oil for domestic and industrial purposes and the discharge of oil and grease into public sewers from garages. They are also useful in reducing the amount of "sleek" caused by grease in domestic sewage, which even in non-manufacturing communities amounts to about 20 grams per capita daily or about 8 tons per thousand population per year.

SKIMMING TANKS ON SEWER OUTFALLS

There is little difference in the arrangement of skimming tanks for municipal sewage. The tanks at Washington, D. C., and Toledo, Ohio, are typical examples.

Washington, D. C.—The skimming tank at Washington has been in operation since 1908. It is actually a head chamber on the two 60-inch inverted siphons under the Anacostia River, which discharge into a 60-inch outfall line to the Potomac River. This tank is egg-shaped, about 22 feet 9 inches in length, and 16 feet in width, and has a depth below the sewage level of from 12½ to 19 feet. There is a platform around the edge of the tank

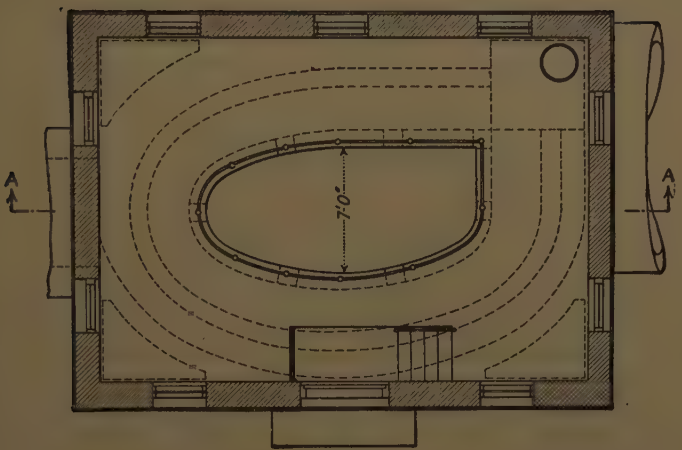
used in removing the material which collects in these tanks, consisting of match sticks, soap, cork, pieces of wood, etc. Skimming is accomplished intermittently, sometimes daily, and at other times three to four times a week by lowering a galvanized iron tray about 2 by 3 feet in plan, with $\frac{1}{2}$-inch perforations. This tray is pulled around on the surface of the sewage until covered by the floating material when it is raised to the working floor and dumped. The material removed amounts to about 100 pounds per 24 hours and is burned with the screenings.

Toledo, Ohio.—At Toledo, Ohio, a skimming tank was constructed in the main outfall sewer discharging in the channel of the Maumee River. The tank is elliptical in shape, about 13 by 21 feet in plan and about 23 feet maximum depth. The floating matters are skimmed off the surface by hand and are either buried or burned. This tank has served an additional purpose in that on several occasions it has retained substantial quantities of oil unexpectedly released from large manufacturing plants and has prevented its discharge through the multiple outlets into the Maumee River. It has been considered worth while, therefore, by preventing criticism of the method of the disposal in the river, even if no consideration were to be given to the removal of greasy substances in regular operation. Figure 21 shows the general arrangement of the Toledo tank.

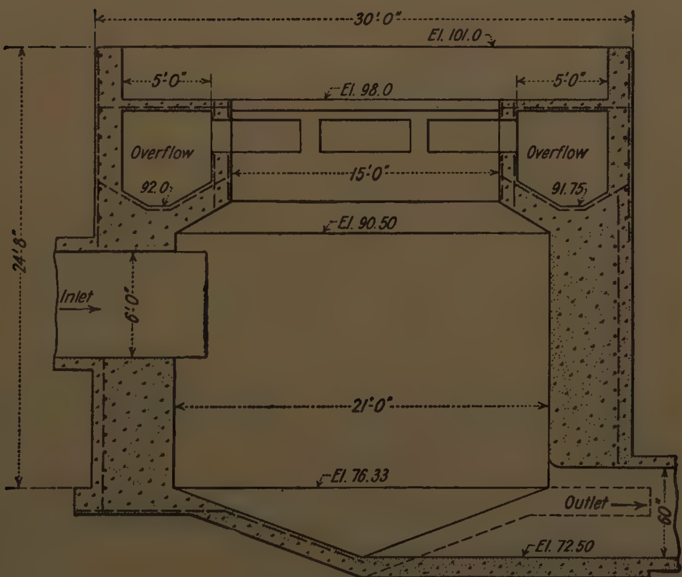
Industrial Skimming Tanks.—Skimming tanks or grease tanks are used at many manufacturing plants, hospitals, hotels, etc., to prevent the discharge of undesirable solids to the sewers. Important installations of these tanks are in use at all places where oil is handled or refined, at many gas plants and at wool scouring plants in this country and abroad.

From the outlets of sewers in the Packinghouse District of Chicago there are skimming plants from which 30 to 80 barrels of grease skimmings have been removed daily, (see Report on Industrial Wastes from the Stockyards and Packingtown of the Sanitary District of Chicago; Volume II, 1921, page 222).

Oil Floating Tanks.—At oil refineries and some large manufacturing plants there is growing recognition of the necessity of retaining oil and oily products in tanks of a size sufficient to allow the oil to rise to the surface so that it can be removed by skimming. At industrial plants where there are settleable solids, such tanks should be a combination of flotation and sedimentation tanks. At plants where the amount of oil is consider-



Plan



Section A-A

FIG. 21.—Skimming tank, Toledo, Ohio.

able, it is not particularly difficult to remove a very large percentage of the oils and grease by proper top and bottom baffled tanks with arrangements for skimming the oil from the top of the liquid. This is ordinarily done with funnels placed just below the surface of the liquid, so that the oil with considerable water is collected and pumped to separating tanks from which the water is allowed to flow back to the entrance of the skimming tank.

Where oil wastes are mixed with other suspended matters and particularly where acids are included in the wastes, the complete removal of oil is not so simple a matter. Solids partially saturated with oil float at all depths in the liquid and are not stopped by scum boards or bottom baffles. At a recent plant designed for the General Electric Company at Schenectady, N. Y., rough skimming of the oil is accomplished in the pump well. Lime is added at the pump suctions to neutralize the acid, and the liquid containing all manner of manufacturing wastes from pottery kilns, floor washings, wire drawing, etc., is pumped to reaction tanks. In these tanks the liquid is constantly stirred, thus breaking up particles which contain oil, and the skimmed liquid is discharged to Dorr tanks where solids are settled out and a final skimming is given.

At the Texas Oil Company's plant at Bayonne, N. J., there is a well designed and operated skimming tank to collect oils. This tank is rectangular, divided into two longitudinal units which are again divided by top baffles into several sections. Bottom baffles are not used as at some other places to prevent the moving along on the bottom of oil soaked heavy suspended matters. At the outlet end of the last section of the tank, arrangements are made to pass the liquid through an excelsior mat to prevent the discharge with the effluent of any suspended solids which may contain oil.

Wool Scouring Wastes.—In this country and abroad much trouble has been experienced with the waste from wool scouring works. In Massachusetts various types of devices to separate the grease produced in cleaning the wool were tried for years with indifferent success. Wool on being scoured loses about one-half its weight. About one-half of the waste material is grease or lanolin and the other half dirt and sheep manure. This mixture is extremely difficult to handle due to the fact that the grease mixed with the other solids does not readily separate

out. Small centrifugal separators apparently are giving successful performance in plants both in Pennsylvania and Massachusetts.

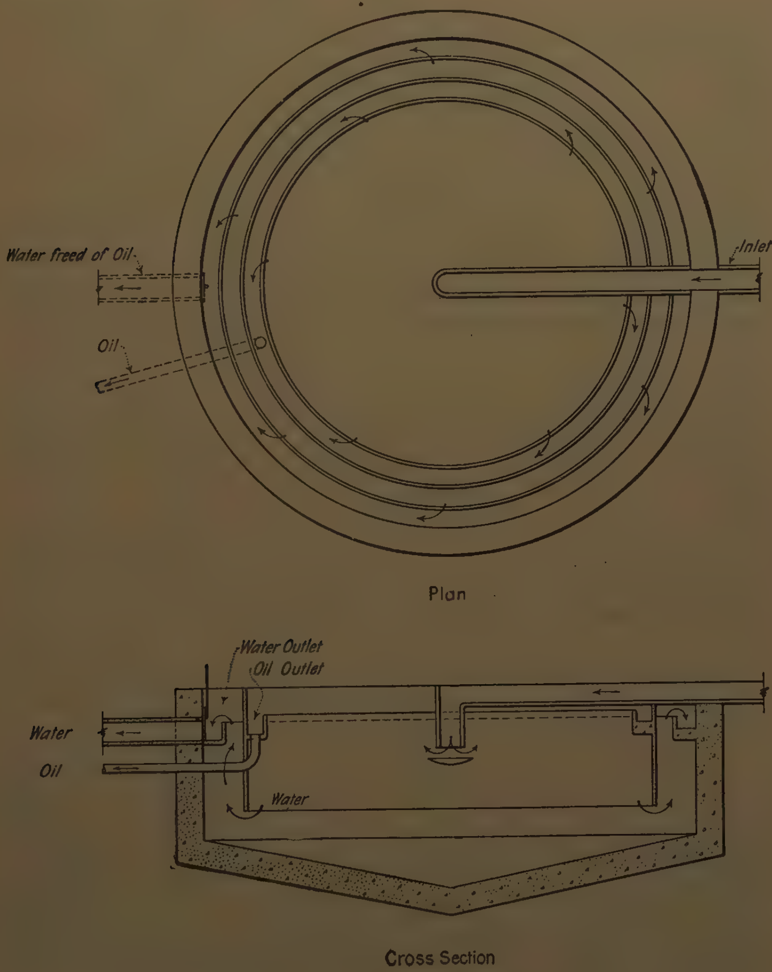


FIG. 22.—Kremer tank.

Bradford, England.—Perhaps one-fourth of all the wool in the world is here handled, making this question of grease removal an extremely serious problem. Various experiments were made to separate the grease, but finally sulphuric acid was adopted in 1901. After precipitation with acid, experiments showed that

sludge could be filter-pressed and the grease extracted and marketed. The dry sludge was also sold as a fertilizer.

At the new Bradford sewage plant being constructed at Esholt the domestic sewage averages about 7 million gallons daily and the trade wastes about 8 million gallons. Here the mixed trade wastes, mostly wool scouring wastes, and the sewage enter precipitation tanks after being treated with sulphuric acid. The grease containing sludge from these tanks, with about 80 per cent of water, is discharged into an underground reservoir. The sludge is pumped from this reservoir and steam-heated. This liquefies the grease, and the separation of the grease and water from the solid matter is facilitated. The liquid from the filter presses, consisting of grease and water, is conveyed to a large cast-iron separating vat where the grease accumulates on the surface and is constantly run off and pumped into the grease purifying vats, the water being drawn off at the bottom. Final purification of the grease is accomplished by boiling it with sulphuric acid to remove water and impurities. The grease rising to the top is packed in barrels or tank wagons for sale.

Kremer Tanks.—In Germany there are a number of tanks of the Kremer type, the purpose of which is to retain the greasy matters. Some cities recover greasy materials which are treated and marketed.

While there are several types of Kremer tanks, they are all operated on the same basis. The simplest type of tank is shown in Fig. 22. The oil and grease separate from the water, rise to the top and flow over weirs which are placed higher than the outlet for the liquid, so that only matters lighter than water will discharge over the outlet weirs. Skimming is effected in this manner automatically. This type of tank is undoubtedly superior to tanks where skimming is done with funnels, provided there is sufficient head so that the water level in the tank can be kept approximately constant.

In this country use is made of Kremer-Schilling grease removing tanks, particularly the smaller cast iron patterns.

Attention is here called to the novel design at Akron, Ohio, for a combination skimming-detritus plant as described in Chapter XV.

CHAPTER XVIII

PLAIN SEDIMENTATION

SYNOPSIS

1. Sedimentation.—This process consists in reducing the velocity of flowing sewage or liquid so that there are gradually separated from the main body of the liquid those suspended matters which have a certain critical specific gravity or hydraulic subsiding value with respect to given conditions.

2. Plain Sedimentation.—This expression applies to the process of clarification whereby solids are deposited by sedimentation unaided by chemicals or by special means to induce deposition of matters which otherwise would not settle. It is generally taken to mean the absence of provisions for the septicization or decomposition of the deposited solids.

3. Critical Velocity.—Of various matters suspended in sewage, some subside promptly when the velocity of flow is reduced; others float on the surface and will not subside at all; others are so fine that they will not settle within a reasonable time; and still others will settle when the sewage is subjected to a sufficiently low velocity for a sufficiently long time. Critical velocities are those which barely permit solid particles to deposit under given conditions.

4. Behavior of Settled Sludge.—Unless the deposited sludge is removed continuously so that the bottom of the tank is kept clean, previously deposited solids frequently appear in the effluent, due to the picking up of particles of low subsiding value at times when the velocities of flow increase. Hence the importance of keeping maximum velocities below critical velocities. Furthermore, unless the deposited sludge is removed either continuously or very frequently, septic action takes place, and gas-lifted particles pass out with the effluent.

5. Terms Applied.—The solids which settle to the bottom are called "sludge." The floating matters are called "scum." The solids which appear in the effluent are termed "non-settleable

solids," and may include colloidal matter which is material in an intermediate state between a true solution and a suspension.

6. Extent of Use.—Plain sedimentation unrelated to chemical precipitation or to septic action was not greatly in vogue for treating raw sewage before the war, particularly in the United States. The high price of chemicals during the war period, however, caused quite a number of tanks throughout the world to be operated as plain sedimentation tanks. Many former single-story septic tanks have also been so operated. In fact this situation is quite general in England where the process is used for storm flows in tanks serving also as storage tanks. Recently sedimentation tanks have come into greater use owing to the successful development of mechanical and other means for removing the sludge without emptying the tanks and also due to the feasibility of using separate tanks for digesting the sludge, as will be noted in Chapter XXIV. In America, the tanks at Baltimore, Md., Gloversville, N. Y. and Toronto, Ont., are rated as plain sedimentation tanks. Newer tanks of this type are those for the Passaic Valley District, near Newark Bay, those at Syracuse, the preliminary tanks of the North Shore activated sludge plant at Chicago and those of several smaller plants operated in connection with separate sludge digestion tanks as at Madison and Hartford, Wis. Plain sedimentation tanks in Europe are numerous. They include those at London, Birmingham, Frankfort, Elberfeld and Hildesheim of the single-story type; as well as two-story tanks, as those at Hochst, Munich and Zurich, from which sludge is removed from the lower compartment every one to three days.

This process is widely used in final settling tanks for clarifying filter effluents and activated sludge as it comes from aerating tanks, as described in later chapters.

7. Efficiency.—By sedimentation it is possible to remove from raw sewage ordinarily from 50 to 75 per cent of total suspended solid matter, from 80 to 95 per cent of settleable solids and about 30 to 35 per cent of total organic matter. The removal of bacteria normally approximates that of the total suspended matter, but sometimes growths of bacteria of certain types develop to such an extent as to disguise completely the fact that many bacteria attached to the suspended solids of the entering sewage must be carried to the bottom of the tank. These growths are not necessarily related to disease germs.

8. Advantages.—Plain sedimentation as a process affords one of the best and cheapest procedures for removing solids which would deposit in watercourses to form sludge banks or which would interfere with oxidizing processes for artificial purification. As a preparatory process it is more efficient than fine screening in that it brings about a removal of practically all settleable solids and about one-third of the organic matter. The process calls for arrangements so that flotation as well as sedimentation takes place, making it feasible to remove floating matter, oil, etc. It is not so expensive as chemical precipitation, which removes about 50 per cent of the organic matter. If during dry seasons such removal is desired, chemicals can be readily used during emergencies.

9. Disadvantages.—When efficiently applied this process requires the frequent removal of large volumes of dilute sludge of a character which generally decomposes quickly. The disposal of this sludge has been a difficult problem for decades, as will be noted from following chapters dealing with septic tanks and digestion tanks, as well as direct means for disposing of sludge on land or at sea.

10. Present Status.—During the past dozen years the status of this process has materially improved, due initially to its economy compared with chemical precipitation. Its present status is now better than ever before on account of improved and satisfactory arrangements for removing sludge from the tanks and of digesting it separately.

HISTORY OF SEDIMENTATION PROCESS

Sedimentation appears to have been first employed with a view to taking advantage on a commercial basis of the fertilizing properties of sewage solids. After abandonment of hopes of realizing the fertilizing value, efforts were made to secure clarification and precipitation with the aid of coagulating chemicals. In the early eighties, or just as the germ theory of disease was coming into recognition and bacteriology rose to the dignity of a science, this was the prevailing method of sewage treatment.

Next came the so-called biological methods of sewage treatment, and beginning about 1895 sedimentation played a prominent part in conjunction with the septic process in single-story tanks. In those days the difference between clarification and sludge treatment was ill defined, and the substantial benefits of

the process of plain sedimentation were more or less confused with biological claims that were but little understood.

During the first decade of this century plain sedimentation came to the front at quite a rapid rate, not only as a separate treatment in connection with the disposal of sewage by dilution, but as a distinctly helpful adjunct to filtration. In preparing sewage for filtration it was found cheaper first to clarify sewage and to employ the resulting higher rates of filtration, generally speaking, than to apply sewage without treatment directly to the filters. Another purpose which it was found to serve in connection with coarse-grained filters is the removal from the final effluent of those comparatively large suspended matters which are unloaded from the filter from time to time and which give the effluent an unsightly appearance.

Plain sedimentation for sewage treatment prior to disposal by dilution and preliminary to filtration gave way to some extent for a time to the use of the septic process in single-story tanks. Beginning about 1910, however, in Germany and America two-story septic tanks of the Imhoff type, and fine screens in some cases, were preferred to sedimentation. Now sedimentation is still extensively used and its popularity has increased. Its scope of usefulness has also been broadened with the advent of the activated sludge process, in which the solids require separation from the final effluent, regardless of whether or not the influent is so treated.

In England plain sedimentation is by far the outstanding method of treating raw sewage and storm water flows.

FACTORS INFLUENCING SEDIMENTATION PROCESS

Influence of Age and Strength.—The fresher and stronger a sewage is and the nearer the sedimentation basins are to the point of its origin, the greater will be the percentage removal of the impurities, especially the suspended matter. As sewage increases in age, some of its suspended matters naturally become comminuted and acquire a subsiding value which is less than before their disintegration. Within certain limits the more dilute a sewage the smaller will be the percentage removal of suspended matters, apparently due in some measure to absence of coalescence of colloidal and other finely divided matters.

Influence of Temperature.—Although temperature is of some significance, it is not so important as might appear because it

affects only a comparatively small percentage of particles. Most of the settleable solids will settle during either winter or summer conditions, and the majority of the non-settleable solids will not subside even under conditions of highest temperature. Stratification of the liquid may occur, with consequent short-circuiting of the flow. A difference of 2.5° F. may cause stratification. As stratification ceases, vertical currents are set up, which interfere with sedimentation.

Economical Limitations.—Obviously sedimentation should be carried out so that it removes settleable solid matter up to the limit where it is the cheapest method, but the process should not be carried beyond this limit.

CHARACTERISTICS OF PLAIN SEDIMENTATION PROCESS IN PRACTICE

Although the next chapter is devoted to plain sedimentation tanks as now used for raw sewage, it is helpful here to record some of the main features of the process.

Velocities in Practice.—For horizontal-flow tanks the average velocity, based on full displacement, should not exceed 0.17 and 0.50 inch per second. Where sludge is allowed to accumulate on the bottom of the tank, average velocities should preferably be kept nearer the lower of these limits. The reason is that, whenever the flow of sewage is increased, there is a disturbance of those particles just above the bottom where conditions are scarcely adequate for complete sedimentation, or even if such conditions are theoretically adequate, some of the particles are readily disturbed. Where the bottom of the tank is kept free from sludge, as in two-story tanks where the sludge continuously drops into a lower compartment, substantially higher velocities are permissible. According to Imhoff the velocities at the highest rate of flow should not exceed a maximum of 2 inches per second, even where the sludge is protected from the scour of bottom velocities.

Effective Depth.—Theoretically the depth of the tank is not much of a factor, but actually shallow tanks behave better. This is probably because, for a given detention period or capacity, the area of the bottom is much greater, thus tending toward less concentration or accumulation of those matters which will just barely subside and which are disturbed by bottom velocities

which scour materials not quite completely or permanently settled. This comment applies to the flat-bottomed single-story tanks and not to the two-story tanks with the trapped slot for the continuous removal of solid matters. Tank depths may ordinarily be adjusted to reasonable dimensions from the standpoint of economic construction.

Sedimentation Period.—In suitably arranged tanks, a period of 1 hour will provide ordinarily for the deposition of practically all suspended solids which will respond to subsidence. Nevertheless, longer periods are quite customary; and in flat-bottomed horizontal-flow tanks used for preliminary sedimentation in England the Ministry of Health requires a tank capacity equal to 10 to 15 hours based on the dry weather flow. With wet weather flows, up to 3 or 6 times the dry weather flow, the period is of course correspondingly reduced. During dry weather some of the tanks are used for storage, or are being cleaned, so that the sedimentation period by no means corresponds to maximum tank capacity.

Baffles.—The purpose of baffles is to cause the velocity of flow to be as nearly uniform as possible throughout the effective cross section of the tank, thus preventing short-circuiting of portions of the flow and guarding against dead spaces. Short-circuiting may result in velocities so high as to permit very little sedimentation. Dead spaces may result in velocities so much below the critical velocities that small benefit accrues from the space occupied. Thus the efficient output of the tank may become needlessly small. Alternate top and bottom cross-baffles have been found effective in promoting uniform velocities. In relatively wide tanks longitudinal baffles or training walls are advantageous.

Inlet and Outlet Connections.—In order to avoid useless dead spaces the inlet and outlet of the tank should be so constructed that the sewage is uniformly delivered to and discharged from substantially the full width and effective depth of the tank. For the outlet a weir is the best form, as this tends to draw the effluent from the full width of the tank and from that portion of the depth which contains the best clarified sewage. The weir should be preceded by a scum board to prevent the passage of floating material, so placed as not to induce excessive velocities between itself and the weir crest. Adjustable weirs are theoretically good, but seldom satisfactory to operate.

Unchecked Inlet Velocities.—The most satisfactory inlet is a number of swing gate orifices, followed by a weir or one or more baffles to check the velocity and distribute the sewage. Unless the inlet velocity is checked, short-circuiting directly to the outlet will take place to a greater or less extent, coupled frequently with a disturbance of deposited sludge. Arrangements for distributing the sewage at the inlet by means of numerous small orifices in a wall or plate are generally unsatisfactory, because the total area of the orifices must be small in order to distribute the flow, resulting in high velocities and large losses of head when maximum rates of flow occur. Inlet and outlet channels should be such as to have scouring velocities and shapes which can be easily cleaned, so as to avoid deposits which would cause odors.

SLUDGE REMOVAL

Methods of Removal.—Tanks of the older type have nearly flat bottoms which require the draining of the tank and hand cleaning by squeegees with the aid of a hose. Tanks of the vertical or Dortmund type, with hopper bottoms, permit the sludge to be removed hydraulically. The more recent tanks have substantially flat bottoms, cleaned by mechanical scrapers. Representative tanks of these types will be described in the next chapter.

Frequency of Cleaning.—In order that decomposition of the sludge may not take place, with consequent gas ebullition and the discharge of gas-lifted particles with the effluent, the sludge should be removed from plain sedimentation basins at frequent intervals. These intervals vary in different cases and in different seasons of the year from a few days to 6 weeks. Tanks which may be cleaned continuously or very frequently without first draining them have therefore marked advantages.

At Worcester, with sewage containing acid wastes, Eddy and Fales found limiting intervals to be 4 to 8 weeks. Schmeitzner stated that at Hanover, Germany, the tanks were cleaned every 2 or 3 days, although cleaning may not be necessary oftener than about every 4 weeks. Elsner stated that sludge may remain in the tanks 3 to 7 days in summer and 8 to 12 days in winter. At Baltimore, Keefer stated that normally the sedimentation tanks should be kept in operation for 10 days to 3 weeks in summer and about 6 weeks in winter. At Gloversville, N. Y.,

Hanmer states that the sludge is removed during about 4 days in each week. At Birmingham, England, sludge is removed weekly.

Quantity of Sludge.—The quantity of sludge per thousand population or per million gallons varies widely with the character of the sewage, the volume of sewage flow, the conditions for sedimentation, and particularly the percentage of water (density) in the sludge.

Tables 44 and 45 show roughly the volumes of sludge per million gallons of sewage and per thousand of population, removed by plain sedimentation under various conditions. For parts per million and grams per capita of suspended solids for ordinary sewages, the reader is referred to Chapter IV.

Table 44.—Gallons of Wet Sludge Removed per Million Gallons of Sewage

Suspended solids in sewage, parts per million	Efficiency of sedimentation, per cent					
	60	60	60	70	70	70
	Water content of sludge, per cent					
	95	90	85	95	90	85
	Gallons of wet sludge per million gallons of sewage					
100	1,170	580	390	1,360	680	450
200	2,330	1,170	780	2,720	1,360	910
300	3,500	1,750	1,170	4,080	2,040	1,360
400	4,670	2,330	1,560	5,440	2,720	1,810
600	7,000	3,500	2,330	8,150	4,080	2,720
800	9,330	4,660	3,110	10,870	5,440	3,620

The above volumes are computed on a uniform basis of a specific gravity of sludge of 1.03, which is a reasonable figure for sludge from separate sewer systems when the sludge contains about 90 per cent water. For sludges having a greater water content than 90 per cent, the specific gravity is ordinarily somewhat less and the volume of sludge somewhat greater than assumed above; and vice versa for sludges having a less water content. For combined sewage, the specific gravity is greater, and the volumes perhaps 2 per cent or so less than for separate sewage.

Separate sewage containing no trade wastes ordinarily contains about 60 to 70 grams per capita daily of suspended soilds; combined sewage may contain 80 to 150 grams. The above

TABLE 45.—GALLONS OF WET SLUDGE REMOVED DAILY PER 1000 CONNECTED POPULATION

Suspended solids in sewage, grams per capita daily	Efficiency of sedimentation, per cent					
	60	60	60	70	70	70
	Water content of sludge, per cent					
	95	90	85	95	90	85
	Gallons of wet sludge daily					
60	185	93	62	216	108	72
80	242	121	81	282	141	94
100	302	151	101	353	176	118
150	454	227	151	529	265	176

volumes are computed on the basis of a specific gravity of 1.03 for 60 grams per capita and 1.05 for the other weights. As stated in Table 44 the volumes correspond to a specific gravity which is reasonable for sludge having a water content of 90 per cent.

Variation in Volume of Sludge.—As will be seen from Tables 44 and 45 the volume of sludge corresponding to a given amount of dry solids varies widely, depending largely upon its water content. The volume which will be occupied by a given amount of sludge, having a given percentage of water, after its water content is changed may be expressed by the following formula:

$$V^1 = V\frac{(100 - P)\,S}{(100 - P^1)\,S^1}$$

where V is the given volume of sludge of given water content;
V^1 is the volume of sludge after change of water content;
P is the percentage by weight of water in sludge V;
P^1 is the percentage by weight of water in sludge V^1;
S is the specific gravity of sludge V;
S^1 is the specific gravity of sludge V^1.

The above formula involves the determination of the specific gravity of the sludge. Since for the range of water content encountered in plain sedimentation the variation in specific gravity will ordinarily be only a few hundredths, this factor may generally be neglected for practical purposes.

CHAPTER XIX

PLAIN SEDIMENTATION TANKS

SYNOPSIS

1. Description.—Plain sedimentation tanks are ordinarily single-story tanks. In a few recent instances, in Europe, they are of the two-story type, in which, beneath the sedimentation compartment, a separate sludge chamber of small capacity is provided for balancing the rate of deposit of the sludge with the rate of removal at intervals of 1 to 3 days.

Exclusive of tanks operated on the fill-and-draw principle, which are practically obsolete, single-story sedimentation tanks are of the following general types:

(*a*) Horizontal flat-bottomed tanks, operated on the continuous longitudinal displacement principle.

(*b*) Horizontal hopper-bottomed tanks, operated on the continuous longitudinal displacement principle.

(*c*) Vertical circular tanks with hopper bottoms, operated with a radial flow from a central inlet to a peripheral outlet.

(*d*) Vertical circular or rectangular tanks with hopper bottoms operated on the upward displacement principle.

Covers are seldom used, although there are exceptions, due to the severity of winter weather or to the desire to hide the sewage from view.

2. Sludge Removal.—Hopper-bottomed tanks were adopted to remove sludge by gravity without drawing off the supernatant liquid. Flat-bottomed tanks require emptying in order to be cleaned by hand. Mechanical cleaning devices for removing sludge continuously, without disturbing regular operations, are a marked feature of recent American practice.

3. Historical Development.—Earliest tanks were flat bottomed and hand cleaned. Vertical tanks date back to the late '80's when they were adopted in the Dortmund District for chemical precipitation. For about a dozen years after 1895, during the height of use of single-story septic tanks, many tanks with flat bottoms and no mechanical cleaning arrangements were built.

During the latter part of this period horizontal flow tanks, with steep sloping bottoms to facilitate cleaning, were built at Frankfort and Elberfeld. Mechanical cleaning devices, operating without putting a tank out of service, are of early English origin, but have had their greatest vogue recently in America. The two-story settling tank, from which sludge is removed from a small lower compartment by gravity every 1 to 3 days, is of recent adoption in South Germany and Switzerland, although it closely resembles the Travis tank in England.

4. Advantages and Disadvantages.—All of the types of tanks noted can give good service. Therefore the relative merits depend largely on local conditions in relation to construction costs and convenience of operation, particularly sludge handling.

5. Present Status.—No type of tank has attained a well defined supremacy for the sedimentation of raw sewage. In England the flat-bottomed tank with hand cleaning prevails; in America the recent designs are for flat-bottomed tanks and mechanical cleaning. In Germany the flat-bottomed tank is rarely seen. Most of the recent designs have sloping bottoms, with hydraulic removal of sludge.

Final, or humus tanks, have for years been ordinarily of the hopper-bottomed type, both in Europe and America. The English are apparently inconsistent with their large deep Dortmund tanks for final effluents, as compared with their large flat-bottomed tanks for preliminary treatment of sewage. Probably this is due to the requirements of the Ministry of Health as to sedimentation period and provisions for storm flows.

TANK CHARACTERISTICS

These can be best set forth by descriptions and figures of representative installations which will be found in this chapter and the one on Final Tanks (Chapter XXXVI). A few preliminary comments, however, may be of assistance.

Horizontal Flow Tanks

Relation of Length, Width and Depth.—According to early German practice the relation of width to length should be within the range of 1 to 6 and 1 to 10. Additional longitudinal walls have frequently been added to European tanks with well defined improvement in the results. In this country shorter tanks are customary; but a ratio of 1 to 1 is rarely used. While long

narrow tanks in parallel may be preferable to a single tank of the same capacity, their efficiency depends upon equal division of the sewage between the tanks. Good results are generally obtained with ratios of 1 to 3 or less.

As to the relation between length and depth, theoretically the shallower the basin the more efficient it is, under some circumstances. Necessity for frequent cleaning to prevent scouring the sludge from the bottom frequently limits the practicability of very shallow basins. Construction features, such as the provision of suitable slopes for sludge removal, add to the minimum depths required. In general, present knowledge does not warrant the use of very shallow tanks.

Theoretically tanks should have greater depth and less width at the inlet than at the outlet end, thus reducing the tendency for the sludge deposits, which are greatest in volume at the inlet end, to be disturbed when increases in velocity occur. This is seldom done; but sometimes baffles are arranged to keep the sludge from moving readily to the outlet end. For the same reason, tanks arranged in series are advantageous.

Vertical Tanks

In a tank in which sewage is applied near the bottom and the clarified effluent removed at the top, the settling of suspended matters seems to promote coalescence or massing together, thus aiding in the removal of the smaller particles. Many of the larger particles travel little or no distance toward the overflow.

The first vertical flow tanks used in this country were built for the World's Fair at Chicago in 1893 and were modeled after those at Dortmund, Germany. They were 32 feet in diameter and about 54 feet high, including the conical tapering bottoms. Sewage was delivered at about the bottom of the cylindrical portion and collected by several troughs at the top. Due to the fact that sludge did not readily slide down the sides of the conical sump, these tanks were not entirely satisfactory in operation.

Vertical tanks are generally capable of giving good clarification, but care is needed in arranging inlets and outlets to avoid short-circuiting the flow. A main advantage of such tanks having conical or pyramidal bottoms is the ability to remove sludge by gravity without drawing off the supernatant liquid. Horizontal flow tanks with hopper bottoms possess the same advantage regarding sludge removal and are generally preferred in this

country to upward flow tanks, even in tanks in which width and length are equal.

Details for Sludge Removal

In plants where the tanks must be drawn down for cleaning, more than one unit is desirable so that service may not be interrupted. Means should also be provided for discharging into another tank the fairly clear liquid above the sludge deposit. Slopes of flat-bottomed tanks should be as steep as local conditions and cost of construction will permit, but not so steep that men cannot readily stand on them. Bottom slopes of 1 per cent or less are common; but 2 per cent or more is better. Where, as is frequently the case, tanks have relatively very flat slopes, much labor is often involved in pushing sludge to the outlet.

Where tanks have steep conical or hopper bottoms, the sludge may be discharged by hydrostatic pressure, with slight or no interruption of service and with practically no removal of the over-lying sewage, through a pipe extending upward from near the bottom of the sump to an outlet pipe located preferably from 4 to 6 feet below the sewage level. In relatively shallow tanks the outlet pipe is frequently taken horizontally, or horizontally and upward, directly from the sump. In the activated sludge process sludge is frequently removed from hopper bottoms by means of air-lift pumps.

The slopes of hopper bottoms required in order that the sludge shall readily move toward the sump varies somewhat with the use to which the tank is put. Where all of the sludge must be removed frequently or continuously without allowing accumulations which would decompose if allowed to remain, very steep, smooth slopes must be provided. Where slopes of 1.0 vertical to 1.0 horizontal are used, the slopes may require frequent cleaning. For best results in prevention of deposits slopes as steep as 1.75 to 1.0 are desirable.

Arrangements for removing sludge mechanically by means of dredges or scrapers have been used for many years in large plants in Europe. Many settling tanks recently built in this country have been equipped with Dorr clarifiers. This device has a number of slowly revolving radial arms at the bottom of the tank provided with short blades or plows inclined to the direction of motion so as to draw the sludge gradually toward a central bottom outlet, along a dished floor having a slope of about 8 to 15 per

cent. It is necessary to maintain a suitable depth of sludge over the moving plows or in the discharge cone at the center of the tank, because without such a sludge seal the over-lying liquid would reach the outlet in undesirably large quantities. Clarifiers are adapted to either round or square tanks. They have been installed at about 40 municipal sewage plants. Of these the largest are those at Syracuse, four tanks for plain sedimentation, each 71 feet square; at Milwaukee, 11 tanks (final) for activated sludge, 98 feet in diameter; and at the Chicago North Side treatment works, 8 preliminary and 30 final tanks for activated sludge, about 77 feet square.

At the Indianapolis activated sludge plant, settling tanks having bottoms sloping toward a central outlet at 1.0 vertical to 3.0 horizontal are provided with revolving elements having sweeping chains which keep the sludge from adhering to the bottom and by producing a slow rolling movement of the sludge assist in concentrating it at the outlet.

Representative Plain Sedimentation Tanks

Baltimore.[1]—At Baltimore, Md., use is made of preliminary plain sedimentation tanks with separate tanks for digestion of sludge. In extending the disposal plant in 1921 it was decided, upon the basis of previous operating experience, to construct plain sedimentation tanks and separate sludge digestion tanks and thus avoid troubles previously encountered with the Imhoff tanks, such as uncertainties of operation, foaming, and necessity for squeegeeing, skimming and removal of scum. The fixed charges and operating expenses were also found to be less than with the type of Imhoff tanks previously installed.

The plain sedimentation tank built at that time does not differ essentially from those of the first installation in 1909. It is an open tank, 420 feet long and 103 feet wide, having a capacity of 3.8 million gallons. It is divided by a cross-baffle wall into 2 compartments, the first of which is 105 feet long, with a depth of from 10.5 to 12.5 feet, and the second 315 feet long and from 13.5 to 15.5 feet deep. Drainage is provided by U-shaped channels, toward which the floor slopes with a grade of about 8 per cent. When the sludge is to be removed, the supernatant liquid is first pumped off; then the sludge, often 4 or 5 feet deep, is

[1] Eng. News-Record, Vol. 87, 1921, p. 654.

broken up by a hose stream. Enough water is added to make the sludge flow to the pump well, whence it is discharged to the sludge digestion tank.

The average period of detention in the sedimentation tanks at Baltimore has been about 3.5 hours, and the removal of settleable solids about 65 per cent. The sludge, before adding water for flushing, contained from 80 to 84 per cent moisture.

Gloversville.—The preliminary settling tanks of the Gloversville, N. Y., trickling filter plant are of the Dortmund or vertical type with conical bottoms, and are about 35 feet in diameter and about 48 feet deep. The sewage is admitted through a central down-pipe, which flares at its lower end and releases the sewage at about the elevation of the top of the cone. The effluent is collected over the sides of cross-channels at the top. The preliminary tanks were designed for a normal upward velocity of about 0.03 inch per second, and a period of detention of about 3.5 hours.

The sewage of Gloversville contains 35 to 40 per cent of tannery waste. In 1922 the average sewage flow was nearly 3 million gallons daily, or practically what the tanks were designed for. The preliminary tanks removed about 85 per cent of the settleable solids, about 68 per cent of the total suspended solids and about 65 per cent of the organic solids. Sludge was drawn from these preliminary tanks about 4 days each week during an average period each time of about 1½ hours. The sludge had a water content of about 95.5 per cent, and amounted to about 6000 gallons per million gallons of sewage treated.

Toronto.—The Toronto settling tanks are covered, vertical, hopper-bottomed tanks of relatively shallow depth. There are 24 tanks, each 25 feet wide and 100 feet long, and each has 4 hoppers. The depth of the vertical portion of the tanks is about 10 feet and of the hoppers about 12 feet. Sewage is discharged downward through an inlet pipe at the center of each hopper, extending about 3 feet into the hopper. The effluent passes out over adjustable baffled weirs arranged along one side of the tank. In 1925, according to Harris, Commissioner of Works, the sewage flow was approximately 72 million U. S. gallons daily from combined sewers serving a population of about 550,000. The maximum rate of flow was 1.42 times the average. The average period of detention with full displacement is now about 1½ hours, and the minimum about 1 hour, after allowing for a depth of 8

feet of sludge. The average removal of suspended solids is about 45 and of settleable solids about 65 per cent.

The tanks are cleaned every 15 days, and in rotation. Septic action begins before the lapse of 15 days, and arrangements are now being made to clean the tanks once in 10 days. Each tank is put out of service for cleaning; the supernatant sewage is returned by pumping to the incoming sewage, and the sludge is pumped to digestion lagoons. After being emptied, the tank is thoroughly hosed down and returned to service. About once in 2 years the grease which has collected on the vertical walls is scraped off. The average daily accumulation of sludge is about 155,000 gallons, amounting to about 2150 gallons per million gallons of sewage treated or about 280 gallons daily per thousand persons. The sludge has a water content of about 91 per cent.

Passaic Valley.—The Passaic Valley Sewerage Commission of New Jersey in 1924 put into operation its trunk sewer and treatment works for collecting and disposing of the sewage from the municipalities situated along the Passaic River. The treatment works consist of 12 settling basins, each about 225 feet long by 25 feet wide, provided with hopper bottoms. The total capacity of these basins is about 1,500,000 cubic feet of which about one-fifth is in the sludge hoppers. They were designed on the basis of 1½ hours detention for the average flow and 1 hour for the maximum flow. The sewage is admitted through gated openings at one end near the bottom of the rectangular portion of the tank, and discharged over a weir at the other end, as shown in Fig. 23. At two intermediate points cross-baffles are provided which skim off the top portion of the liquid and discharge it again at a low elevation.

Syracuse.—The city of Syracuse has recently constructed a sewage disposal plant for treating its sewage by plain sedimentation. The plant includes four sedimentation tanks, which the sewage reaches after it has passed through bar screens and grit chambers. The plant is designed to treat in the future a dry weather flow of 27.5 million gallons daily, with a maximum of double this during storm flows.

The four settling tanks are each 71 feet square at the water line. The sewage enters each tank through six baffled inlet openings spaced uniformly along one side and discharges over a weir along the opposite side. The tanks are equipped with Dorr thickeners for sludge removal as shown in Fig. 24. Their

bottoms slope slightly toward the center, where the depth is 10½ feet. When operating at the average capacity for which they were designed, they have a detention period of 1 hour, corre-

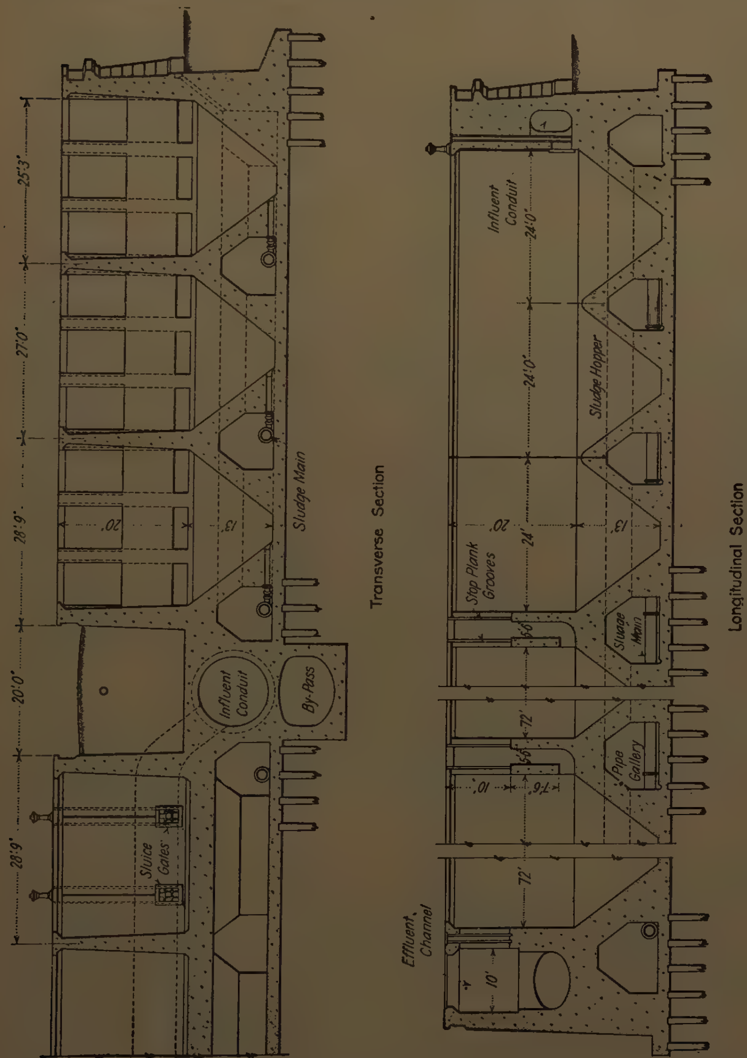


FIG. 23.—Passaic Valley sedimentation tanks.

sponding to a velocity of flow of about 0.24 inch per second. For maximum flows the velocity would be twice this amount. At the present time, the tanks are treating a flow of about 18 million gallons daily. The effluent is dispersed in Lake Onondaga at a

depth of about 25 feet. The sludge removed amounts to about 12,200 gallons per million gallons of sewage treated. The tanks have not been in operation sufficiently long to enable their efficiency in removal of suspended solids to be accurately determined.

Chicago.—At the North Side activated sludge plant, now under construction at Chicago, which is designed for a population of 800,000 and an average daily sewage flow of about 175 million gallons daily, there are 8 preliminary settling tanks. These

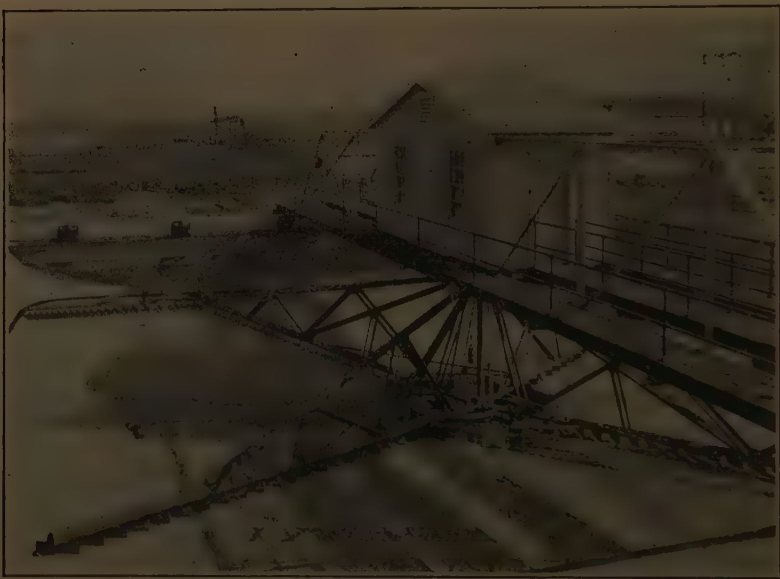


FIG. 24.—Syracuse, N. Y. tank with Dorr thickener.

tanks are about 80 feet square, about 9 feet in depth and have an average detention period of 30 minutes. They are provided with Dorr thickeners for continuous sludge removal, and the sludge is removed by gravity. The sewage enters on two opposite sides of the tank and is removed over the crest of three troughs extending across the tanks. The tanks are designed on the basis of 1670 gallons per square foot per 24 hours at maximum flow, including returned sludge.

Hartford.[1]—At Hartford, Wis., a city of about 4500 people, a sewage treatment plant has recently been installed, including

[1] Eng. News-Record, Vol. 96, 1926, p. 690.

a plain sedimentation tank, a separate sludge digestion tank and a sludge drying bed. The sedimentation tank is 30 by 30 feet in plan, and somewhat more than 5 feet deep at the sides. With an average rate of sewage flow of 400,000 gallons daily, the time of detention is about 2¾ hours. In this tank a Dorr clarifier operates continuously at a rate of one revolution in 8 minutes, moving the sludge to the central cone. A sludge pump, operating about 2 hours during the daytime, discharges the sludge intermittently to the digestion tank. The removal of settleable solids by the settling tank was found by the Wisconsin State Department of Health to be about 73 per cent. The effluent is somewhat milky.

Kremer Tanks.—The Kremer Company, of Germany, installs for preliminary sedimentation, vertical tanks having a deep cylindrical sludge chamber beneath a hopper bottom. The sewage enters at the center of the tank near the top and flows outward and downward beneath a peripheral baffle. The tank is usually square in plan, and has a depth to the top of the sludge cylinder ordinarily between 13 and 20 feet. The sludge chamber is generally 3 to 5 feet in diameter and 6 to 8 feet deep. Sludge is removed every 1 to 3 days.

Stuttgart.—At Stuttgart, Germany, the sewage is settled and clarified, and most of it is then discharged directly into the Neckar River. About two-fifths of the flow passes through Neustadt tanks, one-fifth through a Stuttgart tank of special design and two-fifths through two-story or Emscher tanks.

The Neustadt clarification tanks are six parallel tanks, having a combined area of about 66 by 80 feet, and a depth of about 17½ feet. Sludge is removed from these to two separate sludge digestion chambers by means of sludge conveyors operated by chain drives. The total capacity of the settling chambers is about 415,000 gallons. With a sewage flow of about 5.4 million gallons daily the time of detention was about 111 minutes and the velocity of flow about ⅛ inch per second. The clarification tanks remove about 72 per cent of the total suspended matter and about 84 per cent of the settleable solids.

Höchst.—The settling basins of this German plant, serving a community of 35,000 people having a combined sewerage system, consist of two Travis tanks, of a modified type having very small sludge storage space from which the sludge is removed by hydrostatic pressure. These tanks are shown in Fig. 25. The

two tanks together are about 99 by 66 feet in plan, and about 20 to 23 feet deep. Sludge is withdrawn every 1 to 3 days and transferred to separate digestion tanks. The detention period is about ½ hour on an average dry weather flow of slightly less than one million gallons daily, but the plant is designed to care for five times this amount in wet weather. The sludge as

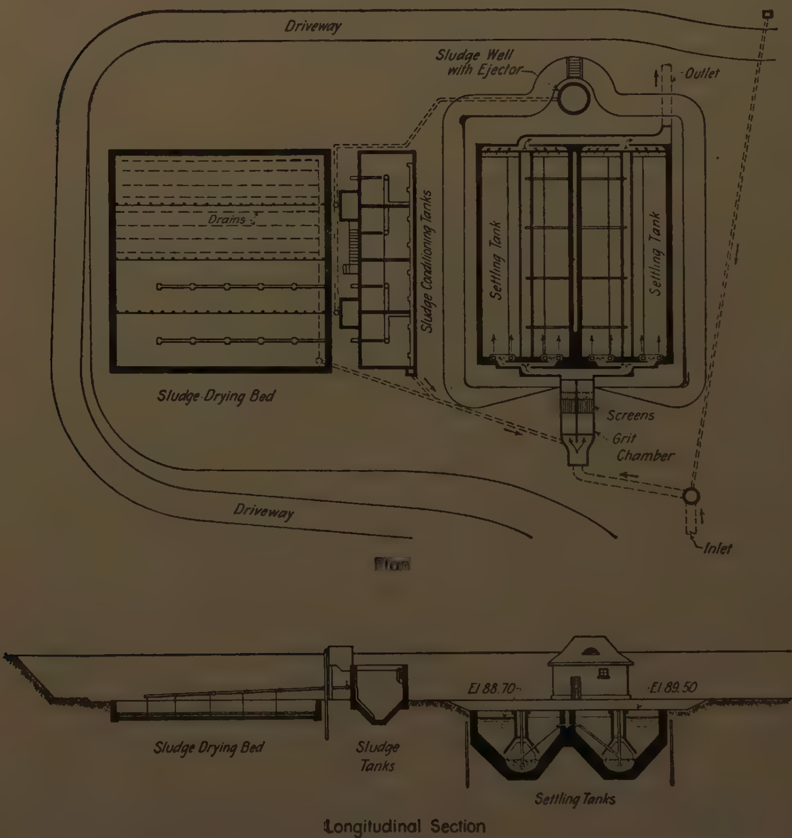


Fig. 25.—Modified Travis settling tank and separate sludge digestion tank, Höchst.

withdrawn from this tank is black and partially digested, and has a slight odor.

Munich.—At Munich, Germany, the sewage from a population at present of 460,000 with future provision for 660,000 people is brought by a combined system of sewers to treatment works consisting of coarse bar screens, grit chambers, clarification

tanks and separate sludge digestion tanks. The present dry weather flow is about 82 million gallons daily, and the storm flow about 228 million gallons daily.

The clarification tanks consist of 16 tanks of the Travis type, and are provided with wooden colloiders. Each tank has two settling compartments, and a single small sludge compartment from which fresh sludge is withdrawn by hydrostatic pressure. The settling compartments are about 18 feet wide, 11.5 feet deep and 82 feet long. Movable baffles are provided throughout the entire settling space to maintain uniform flow.

Zurich.—At Zurich, Switzerland, there was put in operation in 1925 a clarification plant consisting of Travis tanks of a modified type and separate sludge digestion tanks. The city has a present population of about 200,000 of whom 20 per cent are directly connected to the sewers, while 80 per cent still make use of cesspools. The sewage of combined sewers is very dilute and the flow amounts to about 200 to 250 gallons per capita daily.

The Travis tanks are shallow, having very little sludge storage space. This type was chosen on account of high ground water level at the site. There are 12 Travis tank units, each about 17.5 feet deep to the bottom of the sludge sump, 18 feet wide and 43 feet long. The settling compartments are provided with colloiders. The velocity in these compartments is about 0.4 inch per second in dry weather and about 1.2 inches in wet weather.

CHAPTER XX

DISPOSAL OF UNDIGESTED SLUDGE

SYNOPSIS

1. Classification.—Practice in the disposal of sludge without digestion is summarized in this chapter, leaving for other chapters the sludge question in relation to systematic methods of digestion. Sludge disposal for the activated sludge process is also dealt with in a separate chapter.

2. American Practice.—Direct disposal of sludge in an undigested state is not the usual practice in America. Present instances of such disposal, however, include Providence, R. I., and the Passaic Valley, N. J., project, where undigested sludge is barged to the sea. Syracuse, N. Y., mixes undigested sludge with many times its volume of chemical wastes from the Solvay Process Company, and thus secures inoffensive and inconspicuous burial of the sludge. Toronto pumps its sludge to lagoons near the lake shore and, after it has been digested in the lagoons, uses it to fill low ground. Gloversville, N. Y., and a number of New England municipalities dispose of undigested sludge on drying beds of various degrees of porosity, having areas, in the case of the larger plants, of about 1 acre per million gallons daily of sewage flow. Reading, Pa., for years discharged fresh sludge into a lagoon constructed by diking low ground. Many smaller towns have disposed of fresh sludge on land in more or less haphazard fashion by means which might be described as drying beds, lagooning or land treatment, with or without trenching. The details of treatment have varied widely, depending upon the porosity of the soil, the area available and the extent to which farming was practiced on the land.

3. English Practice.—In all but two of the larger cities in England sludge is disposed of without digestion. Barging sludge to sea is practiced by the seacoast cities of London, Salford, Manchester, Dublin, Glasgow and Southampton. Lagooning is the most common method of disposal, and has displaced sludge pressing in many places. Returns from 99 works, as recorded in the 1922 Proceedings of the Association of Managers of Sewage Dis-

posal Works, show that 57 made use of lagooning, 6 lagoons and pressing, 5 lagoons and land treatment, 15 land treatment and 12 pressing. Although at its best lagooning seems to be applied in England to specially prepared porous beds, more or less resembling American sludge drying beds, it is still applied there to the process of pumping sludge onto land and ploughing it in after allowing it to drain. Sludge lagooning and sludge disposal on land are therefore not sharply differentiated processes, but are terms which merge into each other as used in different localities. As an aid to burial on land, trenching is much used at English plants. While many of these methods, when suitably applied, serve their purpose for inland cities, odors may become bothersome where areas are inadequate or operation is neglected. At Leeds, in order to make sure that no sludge nuisance will arise, the sludge, treated with one part per thousand of lime, is pressed, together with detritus and screenings, before being placed on land and covered. At Hanley (Stoke-on-Trent) sludge pressing for the same reason is also practiced.

4. German Practice.—The disposal of sludge without previous digestion is as unusual in Germany as it is in the United States. At Frankfort, from October to April, undigested sludge is delivered to agricultural lands; and during the remaining months it is centrifuged to a spadable condition by Schaefer ter Meer machines, such as have been used at Hanover and Harburg. In earlier years the centrifuged sludge was mixed with city refuse at Frankfort and burned, but this process was abandoned when incinerators were superseded by land treatment for the refuse in 1920. Sludge drying beds are being investigated at Frankfort. Lagooning has been practiced at Elberfeld for many years.

5. Other Methods.—Sludge from plain sedimentation basins has at times been subjected to processes for dewatering, in order to facilitate its ultimate disposal. In some cases this has been done in connection with projected use of the final product as fertilizer. Mention may be made of streamline filters, vacuum filters and of the Dickson process whereby the sludge is fermented with yeast to promote dewatering. So far as known, none of these processes is in regular service for sludge which has not been digested or activated.

REPRESENTATIVE PLANTS

Providence.—At the Providence, R. I., chemical precipitation plant, the sludge from the sedimentation tanks is treated with

lime, screened through a bar screen and raised by ejectors to storage reservoirs. Water rising to the surface in those reservoirs is returned to the main sewage channel. The remaining heavy sludge flows to receivers, and is then forced into presses of the Johnson square-plate type, operated under 60 pounds per square inch pressure. The sludge cakes are 36 inches square and from ¾ to 1¼ inches thick, contain 25 per cent of solids, and require 40 to 50 minutes to form. The cake falls into self-dumping buckets mounted on flat cars. It is hauled to the sea wall near the plant and is dumped into a double-bottomed scow having a capacity of 850 cubic yards which is towed to the dumping ground about 14 miles south of Providence.

During the year 1925, the wet sludge amounted to 21 million gallons, yielding 18,298 tons of cake containing about 4575 tons of dry solids. The principal items of expense for disposal were, for labor, $22,314; lime, $5,433; filter cloth, $3,025; power, $2,672; towing, $3,605. The average sewage flow was 32 million gallons from a population of 242,000.

Passaic Valley.—The sludge removed from the large sedimentation tanks of the Passaic Valley, N. J., project is pumped to scows and taken to sea, where it is dumped at a distance of at least 12 miles from land. The work of carrying the sludge to sea was done by contract at a price of 37 cents per ton, during the year ended in July, 1926, when a new contract was made for 34 cents per ton, assuming 1 cubic yard as the equivalent of 0.86 ton. The estimated quantity of sludge for 12 months is 190,000 tons.

Syracuse.—At Syracuse, sludge is removed continuously from the four sedimentation tanks by means of Dorr thickeners. It is pumped for a distance of over 2 miles to a disposal area where the Solvay Process Company discharges spent lime, acids and other industrial wastes in a volume sufficient to sterilize completely a quantity of sludge 10 times as great as is the Syracuse sludge production. The sludge force main terminates at the outlet end of the Solvay Company's waste pipes, thus mixing the sludge and wastes and providing economical and inoffensive disposal. The supernatant liquid from the lagoons, which finally enters Onondaga Lake, is completely sterilized. During the year ended Nov. 30, 1925, about 80 million gallons of sludge were thus disposed of.

Toronto.—The sludge from the sedimentation tanks at Toronto is digested in lagoons of ½ acre area and 10 feet deep, made by sheet-piling a portion of the Bay which is separated from the

lake by a sand ridge. The lagoons are twelve in number, with a sufficient volume for about 2 years' accumulation of sludge. They are filled in rotation. The effluent from the lagoon which is in the process of being filled discharges into the lagoon next to be placed in service; and then, in turn, into the next in order. Thus the sludge liquid is settled at least three times before passing out into the Bay. In its passage through the lagoons the liquid promotes digestion in them, so that before a lagoon is placed in service it is in an active digestive condition. This is shown by the heavy mat of scum which covers the surface, and by the vigorous ebullition of gas. Approximately 2 months are required to fill a lagoon, after which the sludge is allowed to digest for about a year, when it is pumped by a suction dredge into a sludge deposit area and used as filling. Here it undoubtedly undergoes further digestion. Experience has shown that so long as the mat on the surface of the lagoon is undisturbed, very little odor is evident, and that mainly of ammonia. During the process of pumping from the lagoons there are occasional pockets of sludge which have not been digested, and these give rise to odor. As a rule the odors do not carry far enough or last long enough to occasion complaint. Finally a thin layer of sand or silt is pumped over the digested sludge. The area into which the digested sludge is pumped is almost entirely land locked, but two openings have been made so that there is a free interchange of water between the area and the Bay.

Gloversville.—At Gloversville, N. Y., the sludge from both preliminary and final settling tanks is treated on drying beds. In 1922, with an average raw sewage flow of 2.94 million gallons daily, a quantity of sludge averaging about 17,500 gallons per day from the preliminary tanks and about 6000 gallons per day from the final tanks was thus treated.[1] The four sludge beds, with a total area of about 2.65 acres, are of fine sand, 12 to 15 inches deep and are provided with underdrains. They received about 8.4 million gallons of sludge during the year, which is equivalent to a total average depth of 9.4 feet over the whole area. The water content of the applied sludge was about 95.5 per cent for the sludge from the preliminary tanks and about 94 per cent for the sludge from the final tanks. About 5677 cubic yards of dried sludge were taken from the beds, about 2 per cent of which was hauled away by farmers. The reduction in volume of sludge due

[1] Public Works, June, 1923, p. 199.

to drying was about 86 per cent. The cost of this sludge treatment for the year was about $2800, exclusive of overhead charges; or about $2.60 per million gallons of raw sewage flow.

Brockton.—At Brockton, Mass., sludge is removed from each of the two compartments of the preliminary sedimentation tank about once a week. In 1924, about 2000 gallons per million gallons of sewage flow, or nearly 100 gallons daily per thousand population, were removed from the tank and placed on drying beds. There are three sludge beds, with a total area of 3 acres, and a depth of about 2.5 feet above the underdrains. These beds are some of the old sand filter beds of the plant, from which 2 feet of fine sand were removed and replaced with coarse sand. The wet sludge contained 90.7 per cent of water. The dried sludge removed from the beds contained about 35.6 per cent of water and was used for filling swampy ground, although some of it was given to farmers for use as fertilizer. The volume of the dried sludge was about one-third of that of the wet.

Leeds.—At Leeds, England, the sludge, mixed with screenings and detritus and treated with lime, is pressed and used for filling. It is covered with 3 or 4 inches of turf and some ashes. The city has enough lowland for filling purposes to last 40 years. Some of the sludge is burned and sold to farmers for its lime content, about 100,000 tons having been so far disposed of. A ton of dried sludge produces a quarter of a ton of burned material, which sells for about 10 shillings per ton. About 10,000 tons of unburned sludge were also sold in 1925 at 2 shillings per ton.

Bradford.—At Bradford, England, the sewage contains a large amount of fats principally from wool scouring, and produces a sludge with a moisture content of about 98 per cent. The solids from this sludge are precipitated by means of sulphuric acid and then pressed. The grease is extracted and sold. The dried sludge cake, containing about 2 per cent of nitrogen and sometimes 8 to 10 per cent of fat, is also sold as fertilizer.

CHAPTER XXI

SEPTICIZATION AND GASIFICATION

SYNOPSIS

1. Septicization.—This term is applied to anaerobic decomposition whereby, in the absence of air, intensive growths of bacteria, with the enzymes secreted by them, liquefy and gasify solid organic matters. This process is the opposite of the oxidizing methods described in the later chapters of this book.

2. Humification.—The disintegration of sewage solids until the organic matter is thoroughly rotted out is known as humification. The remaining stable inodorous residue resembles the humus of the forest after removing the carpet of undecomposed leaves.

3. Sludge Digestion.—This process of humifying sludge is now being called sludge digestion. This expression tends to clarify the situation in that septicization seems to be generally associated with the one-story septic tanks widely known to the public for over 30 years. Thus there has been a confusion of plant and process.

4. Liquefaction.—Biochemical decomposition of sludge will cause the disappearance of fully 30 per cent of the total solids in the sludge from the sewage of combined sewers. Relatively more will disappear in the case of separate sewers. This is spoken of as liquefaction, but it also involves gasification.

5. Gasification.—Sludge is gasified biochemically with the gas normally showing about 70 to 85 per cent methane; 10 to 20 per cent carbon dioxide; 0 to 8 per cent nitrogen; and traces of hydrogen. Variations seem to be due to the predominance and relative completeness at the time of sampling of particular types of fermentation.

6. Effect of Temperature.—Judged by gasification sludge digestion is not active below a temperature of about 40° F. and winter results may average only one-third of the average annual output, while in summer activities are 70 per cent or more above

the average. This very important subject will be separately discussed.

7. Effect of Reaction.—Recent evidence would indicate that the rate of sludge digestion, at equivalent temperatures, is a function of the reaction or hydrogen-ion concentration of the digesting sludge. Maximum digestion, within the ranges of non-interfering temperatures, occurs within a fairly narrow zone of hydrogen-ion concentration ranging from pH 7.3 to 7.6. The composition of the gases evolved is also thought to be influenced by the reaction.

8. Gas per Capita.—Sludge from plain sedimentation has yielded about ½ cubic foot of gas per person daily. Where the finely divided suspended matter and colloids are also included, as in the activated sludge process, the digestion of all sludge may increase this figure, which is only a tentative estimate and may be reduced by solids retained in cesspools between the houses and the sewers, or by germicidal wastes in the sewage or by incomplete digestion.

9. Advantages.—Sludge digestion for an adequate period under suitable conditions, after seeding with suitably ripened sludge, will produce an inodorous residue of much lower water content and smaller volume than the original sludge. Digested sludge will drain quickly as compared with undigested sludge. There are several methods of securing the benefits of sludge digestion without over septicizing or otherwise prejudicially affecting the sewage from which the sludge was removed. Furthermore, the gases arising from sludge digestion may be collected so as to insure prevention of their escape into the atmosphere and to provide for the use of this worth-while byproduct.

10. Disadvantages.—These have been gradually and completely overcome as a result of developments made during a period of over 30 years. They earlier involved septicizing of the flowing sewage, escape of odorous gases and the discharge of incompletely digested and bad smelling sludge onto drying beds.

11. Present Status.—For cities not located so as to send sludge cheaply to sea, sludge digestion ordinarily affords the best method of sludge disposal, particularly where adequate facilities for securing substantially complete digestion and good management are available.

The next five chapters record different arrangements related to sludge digestion which as a process is explained in this chapter

without regard to plant facilities. The biochemical principles on which it is founded are discussed in Chapter VI.

HISTORY

Sludge digestion had its origin in cesspools for summer hotels, institutions and country estates where after some months of use on a reduced scale it was found that sewage solids largely disappeared. Mouras first discussed the subject scientifically as then understood in France. The septic tank came into municipal use at Exeter, England, about 1896. Two-story tanks, in which sludge is digested in the lower story, came first into use at Hampton, England (Travis type), in 1903, while the Imhoff type with more ample digestion facilities was first used in the Emscher District in 1907. Separate sludge digestion on a large scale dates from 1912 at Birmingham, England. These procedures had their scientific origin in Clark's work at Lawrence in about 1899.

DIGESTION OF SOLIDS

These processes and arrangements are discussed in greater detail in later chapters. In sludge digestion, decomposition consists essentially of the reduction of complex organic molecules into simpler compounds, in the absence of oxygen from external sources. These end products consist of gases, materials in solution, such as ammonias, undecomposed amino compounds and fatty acids, and stable, peaty organic material of humus character. The biochemical actions ordinarily result in the liquefaction of fully 30 per cent of the total solids originally in the sludge. This figure is reduced or increased depending upon the nature of the sewage solids, temperature, reaction, period of digestion, etc.

From what has been said above, it is not unnatural to expect that the residual product, as measured by the percentage which the weight the sludge found in a tank is of that which has been deposited there, should be quite variable. This is well shown in Table 46, from Winslow and Phelps' Investigations of the Purification of Boston Sewage.

Many years ago it was claimed that all solid matters in septic tanks could be liquefied or gasified. Obviously this is impossible with mineral matters. We also know that scum above the water line dries and is not fully humified. Below the water line liquefaction of scum is uncertain, depending upon the influence of attached gas bubbles. Furthermore, with all organic matter

TABLE 46.—LIQUEFYING EFFICIENCY OF SINGLE-STORY SEPTIC TANKS (Percentage of Deposited Solids Dissolved)

Place	Total solids	Place	Total solids	Organic solids
Birmingham, England	10	London, England	41	71
Exeter, England[1]	25	Boston, Mass.[2]	42	81
Manchester, England	26	Glasgow, Scotland	50	
Ilford, England	30	Hampton, England	..	58
Sheffield, England	30	Saratoga, N. Y.	69	
Accrington, England	35	Boston, Mass.[3]	72	81
Worcester, Mass	39	Exeter, England[4]	80	
Leeds, England	20–60			
Huddersfield, England	40			

[1] Royal Commission studies.
[2] 1905–7 rectangular tanks.
[3] 1909–10 hydrolytic tank.
[4] Early reports from town.

there is a certain portion which is so stable that it will not digest in the course of months.

Most septic tanks have occasional periods of abnormally high gasification. The proportion of residual solid matter is unusually small at the close of such periods. The reverse of this is true just before such periods begin. Table 47 contains further American data on liquefaction of solids in sludge digestion.

TABLE 47.—EFFICIENCY OF SINGLE-STORY SEPTIC TANKS IN LIQUEFYING SUSPENDED SOLIDS

Place	Tank	Period	Per cent of total deposits disappearing
Lawrence, Mass	Tank A	Jan. 1, 1898–Apr. 1, 1904	82.3
Lawrence, Mass	Tank A	Apr. 1, 1904–Nov. 4, 1908	65.3
Lawrence, Mass	Tank B	Nov. 15, 1899–Nov. 18, 1901	74.3
Lawrence, Mass	Tank F	Jan. 27, 1904–Nov. 30, 1907	70.8
Lawrence, Mass	Tank G	May 23, 1904–Dec. 31, 1905	88.7
Lawrence, Mass	Tank H	May 23, 1904–Dec. 31, 1905	83.7
Columbus, Ohio	Tank A	Aug. 16, 1904–June 30, 1905	48.0
Columbus, Ohio	Tank B	Aug. 16, 1904–June 30, 1905	28.0
Columbus, Ohio	Tank C	Nov. 22, 1904–June 30, 1905	67.0
Columbus, Ohio	Tank D	Feb. 18, 1905–June 30, 1905	39.0
Columbus, Ohio	Tank E	Mar. 9, 1905–June 30, 1905	50.0
Waterbury, Conn	Tank 2	Sept. 3, 1905–Nov., 1906	44 0
Waterbury, Conn	Tank 3	Sept. 3, 1905–Nov., 1906	64.0
Gloversville, N. Y	......	May, 1908–June, 1909	54.4
Plainfield, N. J	......	Mar., 1910–Jan., 1911	39.1

It is probable that some of the foregoing data show disappearance by liquefaction and gasification of some solids that may have escaped in the effluent. However, as a whole the data are of value in showing that the digestion of sludge will effect a substantial reduction in its solid contents.

Composition of Sludge.—There are some variations due no doubt to the diet of persons connected with the sewers. But the chief differences are due to street wash and industrial wastes. When the latter items are duly considered, sludge digestion may be compared on a population basis in connection with the treatment processes used.

Period of Seeding and Ripening.—The time required for sludge digestion to become established on a thoroughgoing basis ranges from 6 weeks to 6 months, depending largely on temperature and reaction. Settling tanks if uncleaned will show considerable gasification in a week or 10 days. After this, digestion is more active, although the regimen of procedure may be disturbed by winter temperatures and by an unfortunate emptying of a "well seeded" tank, biochemically speaking. That is to say, with two sets of tanks of equal size and treating exactly the same volume and composition of sludge, one set might serve well its purpose, while poor management might handicap the other set through poor handling as to seeding with ripened sludge.

CHARACTERISTICS OF DIGESTED SLUDGE

Freedom from Odor.—Well digested sludge has a brownish black color, with a slight tarry odor. It is an entirely different looking and behaving product from the foul smelling sewage solids before digestion or humification.

Reduced Volume.—The 30 per cent or more of solids digested makes of course for a corresponding reduction in volume of sludge. Fortunately digestion brings about another characteristic and that is a smaller percentage of water. Undigested sludge contains usually from 90 to 95 per cent of water, while well digested sludge averages about 85 per cent. On this basis digestion would effect a reduction in volume of about 50 per cent; from 7.5 per cent solids (92.5 per cent water) to 15 per cent solids (85 per cent water). This is an important item both as to tasks of disposing of wet sludge and of estimating the volume of digestion space to be provided in order to see that an adequate period is assured for digestion to proceed to substantial completion.

Entrained Gas.—Incident to sludge digestion is gas production. The bubbles become entrained in the sludge as removed from the digestion tank. If digested sludge is allowed to stand in a container, the gas bubbles rise to the top and carry the solid matters with them. Below is the clear subnatant liquid. The entrained gas makes it easier to dewater the sludge on drying beds.

GASIFICATION

The gases resulting from the normal decomposition of sludge either in two-story or in separate sludge digestion tanks usually consist of methane, carbon dioxide and nitrogen, with traces of oxygen and hydrogen under certain conditions. The carbon dioxide results through the destruction of organic material by bacterial life and their enzymes. It is the end product of such organic decomposition beyond which further oxidation does not take place. It may also be produced as a byproduct in various processes, as for example in the fermentation of sugar.

Methane is produced through the decomposition of starches, cellulose and other carbohydrates, as well as from protein, by means of various groups of organisms. It may also be formed through the action of hydrogen on carbon dioxide when in the presence of catalyzing bacterial enzymes.

Significance of nitrogen, hydrogen and oxygen has been discussed in Chapter VI. Further details on their production are not essential at this point.

COMPOSITION AND AMOUNT OF GASES PRODUCED

The best of the older data available in the United States as to the composition of gases released from septic tanks or sludge digestion were secured some 20 years ago by Kinnicutt and Eddy at Worcester. Weekly analyses were made for a year. The average results are shown in Table 48, and for purposes of comparison there are also included results obtained by Rideal on Exeter tanks and data from the Lawrence Experiment Station obtained by Gill.

The Worcester data showed some variation in the content of the gases at different seasons of the year. Methane rose to 81 per cent during the summer, and carbon dioxide (CO_2) to 8.85, while nitrogen fell to 8 per cent.

TABLE 48.—PERCENTAGE COMPOSITION OF SEPTIC TANK GASES

	Methane	Nitrogen	Carbon dioxide	Hydrogen	Other gases
Exeter, England	20.3	61.2	0.3	18.2	
Worcester, Mass.	75.2	17.4	5.9	0.3	1.4
Lawrence, Mass.	78.9	16.3	3.4		

Clark and Gage (1908 report, Massachusetts State Board of Health) also developed analytical data on the gases produced from septic tanks and the fermentation of solids. Their quantitative results follow in general those noted herein. Their data, both in 1908 and later, indicate that there is a striking difference in composition of gases under different conditions of production.

Jesse[1], Fales[2] and Hommon[3] recorded the results of analyses of many samples of gas, but the most extensive investigations in America have been made by Rudolfs[4] and his associates. Their work was begun in 1922 and is still under way, for the most part at the Imhoff Tanks at Plainfield, N. J. A comprehensive summary of some of this work on the influence of temperature and reaction is given at the end of this Chapter. Here it is sufficient to add that credit is also due Rudolfs for gas analyses under a wide range of operating conditions. He found no hydrogen in 50 samples, but discovered that the hydrogen-ion concentration gives a true index of the total activities in a digestion tank. When the contents were acid, that is, below pH 7.0, foaming occurred but subsided when the hydrogen ion concentration was above the neutral point. A reaction of pH 7.3 to 7.6 is the optimum for digestion. At 8.2 or above, little digestion occurs. Rudolfs also traced the relation between hydrogen ion concentration and carbon dioxide, ammonias, carbonates and other indices of different stages of digestion.

Imhoff states (1924) that in the Emscher District about 8 liters of gas per day, or 0.3 cubic foot per day, or 3 cubic meters

[1] University of Illinois Bulletin, 1912, Vol. 9, No. 20, p. 47.

[2] Annual Report, 1912, Superintendent of Sewers, Worcester, Mass.

[3] Proceedings, 1916, American Society for Municipal Improvements.

[4] Reports for 1923, 1924 and 1925, Joint Project of New Jersey Agricultural Experiment Station and New Jersey Department of Health.

per year, are contributed by each inhabitant connected to the sewers. The gases have the following general composition:

	Per Cent
Methane (CH_4)	80–85
Carbon dioxide (CO_2)	7–20
Nitrogen (N)	0–8
Hydrogen (H)	0

Blunk and Sierp contribute interesting data on the composition and amount of gases produced through a study of the operations of an Imhoff tank in the Emscher area. Their results are shown in Table 49.

Table 49.—Gas Content from Imhoff Tank
(Figures in Per Cent)

1924	8/23	8/31	9/2	9/3	9/7	9/8	9/9	9/10	9/12	9/16	9/17	9/20	9/22
Methane	65.4	67.2	66.2	Sludge Removed	77.9	77.5	72.9	64.8	69.0	72.0	71.8	69.8	69.9
Carbon dioxide	30.0	30.7	30.6		16.3	20.4	23.3	23.0	25.0	24.4	23.8	25.2	26.2
Oxygen	....	0.5	0.4		0.7	0.4	0.9	0.8	0.4	0.8	0.4	0.4	0.2
Nitrogen	4.6	1.6	2.8		5.1	1.7	1.3	5.1	1.9	0.4	2.8	3.4	3.7
Hydrogen	....	....	....		....	....	2.5	6.3	3.7	2.4	1.2	1.2	

More recently Buswell and Strickhouser have added to the meager data available on sewage tank gases. Their findings are of interest, although the purpose of their study was primarily to study the variations in composition of gases from sewage tanks which were behaving differently. Their results are shown in Table 50.

It is reasonable to conclude from the data, experimental and otherwise, so far collected, that, in general, gases which result from decomposition of sludge have the following components in percentages:

Methane	65–90
Carbon dioxide	5–35
Hydrogen	0–10
Nitrogen	0–8

In well ripened sludge the results of experience on the continent of Europe seem to warrant the following assumptions of percentage composition of resultant gases:

Methane	80
Carbon dioxide	20
Hydrogen	0
Nitrogen	0–8

TABLE 50.—ANALYSES OF GASES FROM IMHOFF TANKS

Date	Source	Location	Per cent CO_2	Per cent H_2S	Per cent O_2	Per cent H_2	Per cent CH_4	Per cent N_2	Remarks
		From Foaming Tanks							
9/ 2/24	Decatur	Tank 3, middle vent	29.4	0.1	0.0	0.0	66.6	3.9	
9/ 9/24	Decatur	Tank 1, middle vent	29.3	...	0.0	0.0	67.5	3.2	
9/ 9/24	Decatur	Tank 1, middle vent	28.5	...	0.0	0.0	65.7	5.8	
9/26/24	Decatur	Tank 1, middle vent	28.3	...	0.0	0.0	67.7	4.0	Foaming only slightly
10/ 4/24	Highland Park	East tank, effluent end	24.0	...	0.0	0.0	72.7	3.3	Park Avenue plant
10/ 4/24	Highland Park	East tank, inefluent end	24.7	...	0.0	0.0	71.3	4.0	Park Avenue plant
7/14/25	Urbana	North tank, middle vent	22.6	...	0.6	0.0	62.5	14.3	Beginning to foam
10/13/25	Urbana	Tank 3 resting, middle vent	19.8	0.0	0.3	0.0	68.7	11.2	
10/15/25	Urbana	Tank 3 resting, middle vent	20.1	0.0	0.3	0.0	68.0	11.6	
		Average	25.2	...	0.1	0.0	67.8	6.8	
		From Non-foaming Tanks							
9/ 2/24	Decatur	Tank 1, side vent	25.9	0.1	0.0	0.0	71.4	2.6	
9/ 9/24	Decatur	Tank 3, middle vent	28.5	...	0.0	0.0	63.0	8.5	
9/26/24	Decatur	Tank 1, middle vent	23.6	...	0.0	0.0	72.8	3.6	
10/ 4/24	Highland Park	Side vent	3.3	...	0.0	0.0	78.2	18.5	Deerfield plant
5/ 1/25	Urbana	North tank, middle vent	16.2	...	0.6	0.0	60.0	23.2	
5/ 7/25	Urbana	North tank, middle vent	11.6	...	0.0	0.0	67.2	21.2	
5/19/25	Urbana	South tank, middle vent	10.0	...	0.2	0.0	70.7	19.1	
7/28/25	Urbana	South tank, middle vent	15.3	...	0.3	0.0	68.6	15.8	
		Average	16.8	...	0.1	0.0	69.0	14.1	
		From Septic Tanks							
8/22/24	Urbana	East tank	14.0	...	0.0	4.5	66.4	15.1	
8/26/24	Urbana	East tank	14.3	0.5	0.0	5.0	64.3	15.9	
8/29/24	Urbana	East tank	13.6	...	0.0	3.5	72.5	10.4	
7/14/25	Urbana	East tank	17.0	...	0.0	0.0	78.0	5.0	
		Average	14.7	...	0.0	3.3*	70.3	11.6	

* Includes analysis of July 14, 1925, when no hydrogen was found.

Inasmuch as the percentage of carbon dioxide is of importance, in that any increase therein reduces the calorific value of the methane, it is important to attempt to keep the carbon dioxide at a minimum. The solubility of carbon dioxide in water, in contrast to the low solubility of methane in the same medium, has given some clue to the possibility of reduction of carbon dioxide in such gases. Methods of purification of sludge digestion gases will be discussed in a later chapter.

CONTROLLING FACTORS OF GAS PRODUCTION

Temperature.—The effects of the temperature and the season of the year upon the rate of gasification were studied some years ago by Kinnicutt and Eddy at Worcester. Their experiments were conducted in a closed tank and the gas was measured with a wet gas meter. The volumes of gas produced during each month, in percentages of the annual mean, are shown below:

January	30	July	140
February	62	August	167
March	48	September	170
April	51	October	116
May	100	November	115
June	148	December	65

Johnson, in similar observations at Columbus, Ohio, reported the following data:

Month 1905	Average temp. of applied sewage, ° F.	Average quantity gas evolved daily, cubic feet	Percentage of gas to volume of sewage settled
March	51	29	3.1
April	58	14	1.5
May	61	41	4.4
June	66	50	7.7

Clark and Gage[1] give similar data upon gas production in septic tanks at Lawrence, in Table 51.

It is interesting to compare the above data with more recent observations in 1924 by Sierp and Blunk, working independently in Germany. Their observations are shown in Fig. 26, while Fig. 27 shows data by Imhoff on the temperature of sewage and sludge.

[1] Report, Mass. State Board of Health, 1908, p. 493.

TABLE 51.—GAS PRODUCTION IN LAWRENCE SEPTIC TANK

	April 21 to May 1	May 2 to May 22	July 10 to July 20	Oct. 4 to Oct. 6
Average storage in tanks, hours.....	28	21	28	23
Average temperature in tank, degrees..........................	51	52	74	65
Cubic feet of gas formed per million gallons of sewage passed........	6,100	8,400	11,300	6,000
Cubic feet of gas formed per thousand gallons tank capacity............	5.3	9.5	9.5	5.3
Cubic feet of gas formed per cubic foot of sludge in tank............	0.71	1.27	1.27	0.71

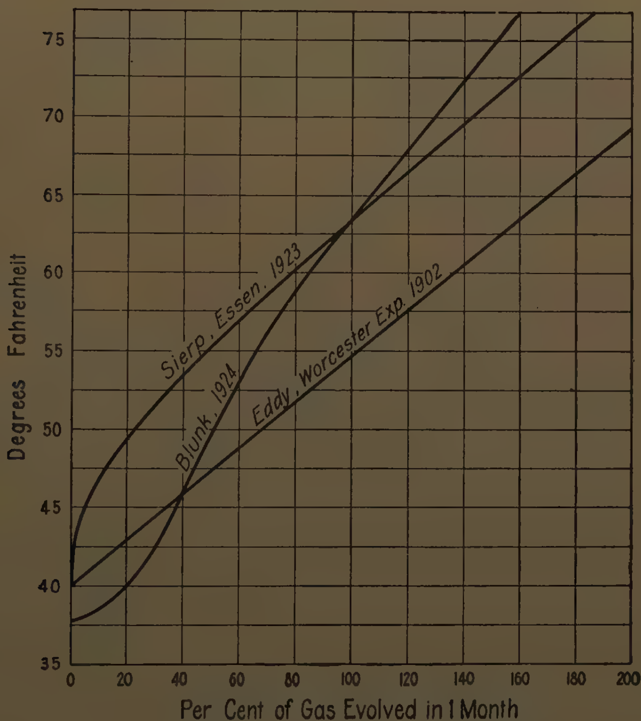


FIG. 26.—Effect of temperature on gas evolution.

It is of course not surprising that, in the digestion of sludge, temperature should play an important part, as the entire process is a biochemical one in which biological life, with its well known sensitiveness to temperature variations, is the controlling feature. Blunk has confirmed this fact quite clearly in a recent discussion (1925) by actual measurement of gas production at the sewage treatment plant of Essen-Nord. His results are presented in Figs. 28 and 29.

He has produced additional interesting data by a series of laboratory experiments, the conclusions of which are worth noting at this point, although Blunk himself emphasizes the

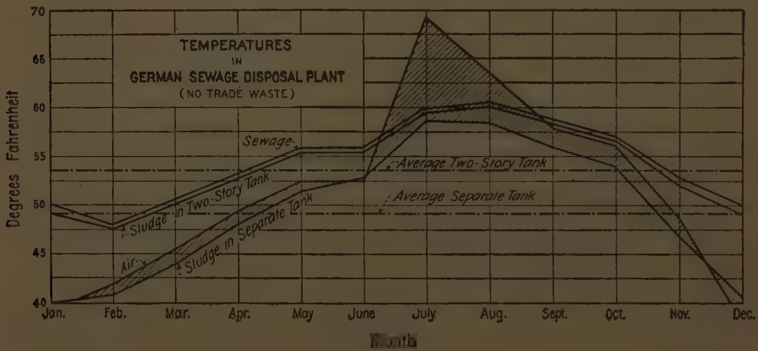


FIG. 27.

importance of having such laboratory data carefully confirmed by further large-scale plant observations. He finds, as a result of his observations on the treatment plant at Essen-Nord, that at a temperature of 17½° C. an average of 2½ cubic meters of gas per ton of dry substance is produced. By further observations in a separate sludge digestion chamber at the treatment plant of Frohnhausen, he finds that decomposition practically ceases at temperatures below 4° C. As the temperatures rise above this point, the following quantities of gas result per ton of dry sludge:

Temperature, °C.	Cubic Meters Gas per Ton Dry Material
5	0.67
7.5	1.0
15	2.0
17.5	2.5

At higher temperatures it was found that the same quantity of gas is produced in half the time at 25° C. as at 15° C., or twice the amount of gas is produced at the higher temperature in the

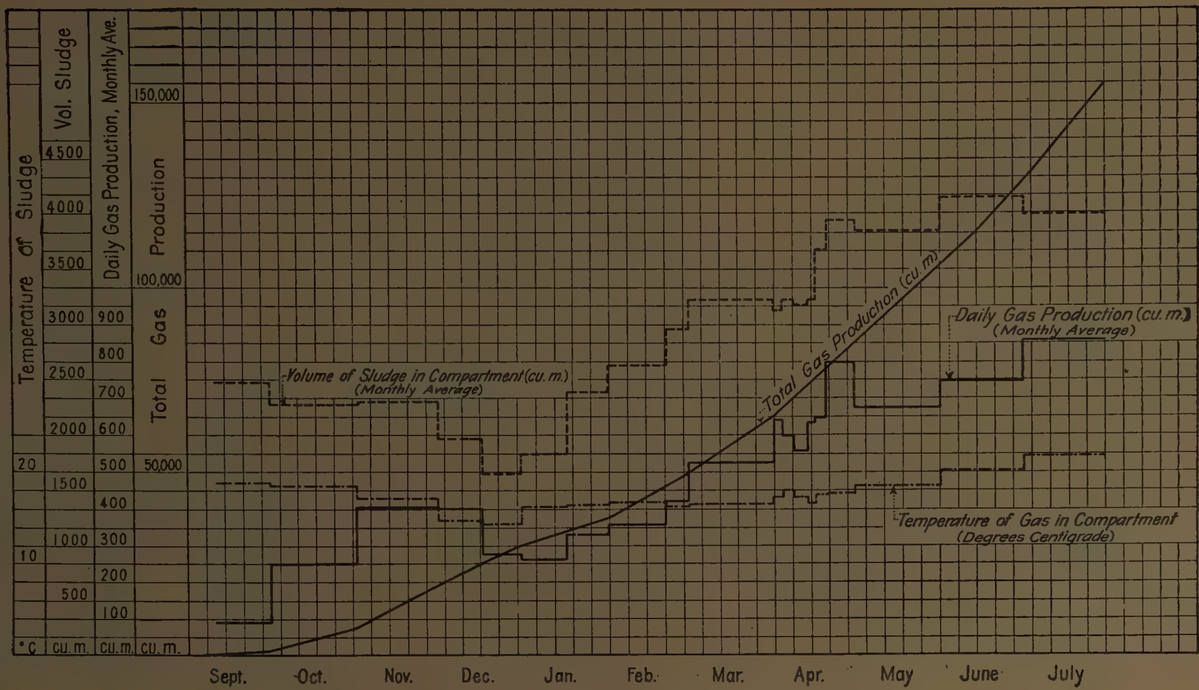


FIG. 28.—Gas production in the treatment works, Essen-Nord, Germany.

In 10 months 150,000 cubic meters of gas were produced in the city of Essen. A daily average showed 195 tons (metric) of dry material to be disposed of in the compartments. On those days when 500 cubic meters of gas were produced one kilogram of dry sludge produced $\frac{500,000}{195,000}$ = 2.5 liters (approximately) of gas at an average temperature of 17.5° C.

same time as at the lower temperature. These observations are graphically presented in Fig. 30.

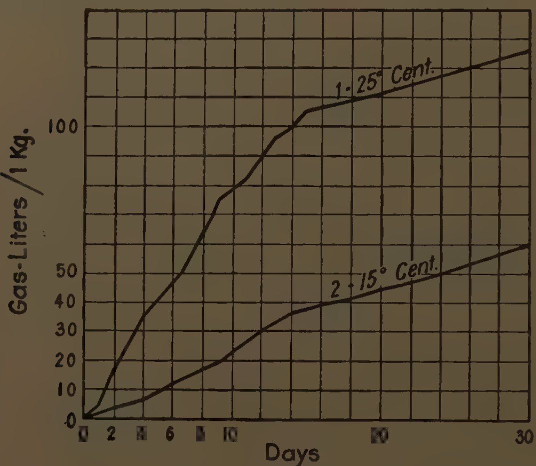


FIG. 29.—Daily gas production.

Line 1 shows the gas production per kilogram of dry material held at a temperature of 25° C. during 30 days of decomposition—namely 124 liters, or about 4 liters per kilogram per day.

Line 2 shows the results of experiments on the same sludge at a temperature of 15° C. over the same period of time. Production—60 liters of gas or 2 liters per kilogram per day.

1	2
33 kilograms fresh sludge.	100 kilograms fresh sludge.
33 kilograms stale sludge.	100 kilograms stale sludge.
Dry material 9.91 kilograms.	Dry material 29.73 kilograms.
Temperature 25° C.	Temperature 15° C.

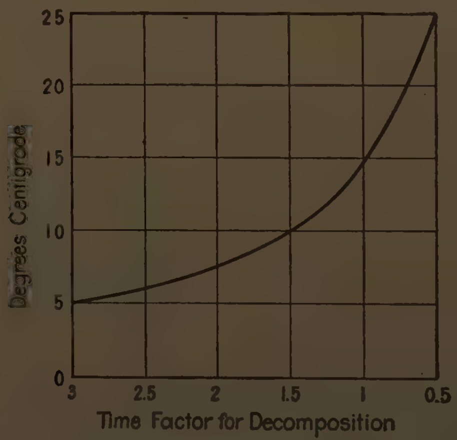


FIG. 30.—Influence of temperature on decomposition.

Evidence, on a laboratory scale, indicates that gas production and liquefaction or decomposition of sludge do not proceed

simultaneously and that the optimum temperature for gas production is actually not equivalent to or comparable with the most desirable temperature for liquefaction of solids. If confirmed by later observations, it would establish the range within which it is desirable to maintain sludge decomposition for maximum gas production. It is interesting to refer to Fig. 31 where these facts have been set forth in graphical form as the result of experiments by Sierp in 1924. He indicates that, while the most favorable temperature for sludge digestion or decomposition is 37° C., for gas production it reaches its maximum value at 25° C. Such favorable results, how-

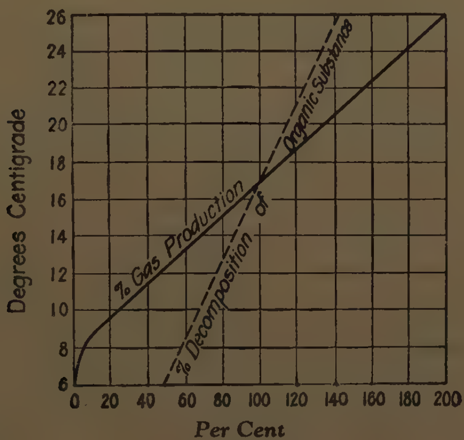


FIG. 31.—Relation between temperature, gas production and decomposition of organic matter.

ever, are obtained in sludge digestion even at 25° C. that there is no particularly practical advantage in raising the temperature of the sludge digestion chamber beyond 25° C. Sierp further points out that, aside from disadvantages in cost, there may be some danger in raising the temperature of sludge digestion above 25° C. through the probable interference with the life cycle of the gas producing bacteria. These observations are suggestive, but as indicated elsewhere, they should be subjected to careful scrutiny and confirmation by other investigators.

Rudolfs points out that in German tests at lower temperatures the period of observation did not permit all the organic matter to be digested. Reference is here made to Rudolfs

publications and the summaries given at the close of this chapter.

Kind of Organic Matter.—That the quality of the organic matter is of importance is also shown by Clark and Gage in the 1908 report of the Massachusetts State Board of Health. The data are shown in Table 52, but there is no definite explanation as to why different kinds of sludge produce different volumes of gas. A longer period of digestion might have affected the results differently. It is also to be borne in mind that besides differences in organic matter there are differences noted in the seeding of bacteria and complicated biological factors of symbiosis and antagonism.

TABLE 52.—AMOUNT OF GAS PRODUCED BY FERMENTATION OF SLUDGE

Source of sludge	Days	Per cent organic matter in sludge	Cubic centimeters of gas formed per gram of	
			Sludge	Organic matter
Tannery sewage	61	51	0.00	0.00
Lawrence sewage	26	84	0.34	0.40
Lawrence sewage	21	78	5.80	7.45
Septic tank F	30	46	4.14	9.00
Effluent of trickling filters Nos. 135 and 136	30	44	2.80	6.37
Effluent of trickling filter No. 248	60	45	54.40	121.00

RESEARCH DATA ON SLUDGE DIGESTION

Since the foregoing part of this chapter was set in type, the authors have received an advance copy of the Proceedings of the Eleventh Annual Meeting (March 26, 1926) of the New Jersey Sewage Works Association. It contains notes of an informal discussion of unusual value on this subject by Rudolfs of the New Jersey Sewage Station and by Baity, Rockefeller Foundation Research Fellow in the Harvard Engineering School. The latter's work for 18 months on sludge digestion gave results quite in harmony with those of Rudolfs and his staff. The main findings are set forth in the following excerpts:

Rudolfs' Statement.—The poorest digestion prevails in any tank, whether it is an Imhoff tank, separate sludge digestion or septic tank, when the materials in the tank are slightly acid,

or when they are very alkaline. The acidity in these tanks is sometimes not enough to be determined by titration. The acidity is caused by carbon dioxide gas in solution, partly decomposed material that is in suspension and by acid materials which are formed in the process of decomposition, especially organic acids. These are the findings of the last two or three years. Knowing that acid is detrimental to most rapid digestion it follows that different reactions influence digestion differently. For instance, if we have an acid material, digestion is very slow; if the material is very alkaline digestion is slow; but if it is near neutrality slightly on the alkaline side, or what we call the optimum reaction, digestion is rapid. What determines then the rapidity of the digestion? One important factor is optimum reaction. The optimum point, as we have expressed it in pH values, is about from 7.3 to 7.6 with properly seeded material. We can add small quantities of lime to adjust the incoming fresh solids and, if necessary, to bring the sludge in the tanks to the desired optimum. When I said properly seeded material I had in mind the correct relation between incoming fresh solids and ripe sludge present.

Another point is that liquefaction of material or gasification of material can be induced by certain reactions; in other words, if we have a certain reaction we will have liquefaction to a fairly stable material, or if we change the reaction, we have gas formation with the same material at the same temperature and with the same conditions. As far as I am aware this fact has not heretofore been established or recorded.

I said a moment ago that small quantities of lime are necessary to adjust the reaction. For the Plainfield sewage about 3 or 4 pounds per million gallons of sewage daily were sufficient to adjust the pH of the sludge to 7.3 and about 25 pounds per day per million gallons to 7.6. By doing so, that is by adding this quantity of lime to the Plainfield sludge which has a certain acidity, we decrease the time of digestion practically by half. Say, for instance, that it takes 100 days to digest a sludge of a certain concentration; by keeping it at the optimum reaction it will take from 50 to 60 days to accomplish the same kind of digestion.

Baity's Experience.—In our preliminary experiments on the effects of temperature it was observed that rapid digestion of the sludge by gasification took place when, and only when, the reaction was between pH 6.9 and 7.4. Well ripened sludge

drawn from the Fitchburg tanks also showed a pH value of around 7.2 or 7.4. The gas producing organisms seemed to require this particular environmental condition before they would become active and accomplish their work. They would lie dormant in a mixed and seeded sludge for months, waiting for the toxic acid products to be neutralized by the slowly formed alkaline products and for the creation of an environment that would suit their fastidious tastes.

We prepared three flasks containing mixtures of 2 parts, by weight, of fresh Brockton sludge to 1 part of fully digested Fitchburg Imhoff sludge. This mixture contained 6.5 per cent dry solids, of which 53 per cent was organic and 47 per cent mineral. One flask was left in its natural condition, as a control; to the second was added 1 per cent, on the basis of net sludge weight, of powdered calcium carbonate; and to the third enough hydrated lime was added at intervals to maintain a reaction of about 7.2 or 7.4. All of these flasks were incubated in the same water bath maintained at a constant temperature of 20° C. The technique employed was the same as already mentioned for the temperature experiment, and, with the exception of bacterial counts, the determinations were the same. Lime was added through the vent tube of the flask, and samples for pH determination were pipetted through the vent tube without disturbing the seal. The experiment was carried through to complete digestion of the lime-adjusted sludge.

Throughout the experiment the rate of gas production in this sample dosed with calcium carbonate was much greater than in the control. With the lime-adjusted sludge some difficulty was experienced in keeping the reaction adjusted during the initial stages of the experiment. Acid digestion tended to reduce the pH, making additional applications of lime necessary. Care had to be exercised in adding the lime, as it was found that very small amounts would arrest gas formation. Later the desired reaction was maintained without further addition of lime. Upon starting the experiment there was no gas produced for several days, this time probably being required for development of the flora and its adjustment to the environment. But immediately thereafter rapid gasification began and continued until digestion was complete, at a rate of about 8 to 10 centimeters per day per gram of dry organic solids. The peak rate of production was 14 centimeters per day per

gram of organic matter, and occurred at pH 7.5. Analyses of the gas produced from the control showed it to be of the same CO_2 and CH_4 content as that of the previous experiments when compared on the basis of prevailing reactions. Strangely enough, the gas from the sludge treated with calcium carbonate did not show any lower CO_2 content than gas produced from other samples at the same pH reaction, indicating that there is little chemical action between the evolved CO_2 and the carbonate. The gas produced from the sludge with reaction controlled to 7.4 with lime showed from the beginning a low CO_2 content with high CH_4. Its composition compared favorably with that of gas produced at optimum reaction in other experiments, about 8 per cent carbon dioxide and 85 per cent methane. The total amount of lime required for adjustment was about two-thirds of one per cent of the weight of wet sludge.

EFFECT OF TEMPERATURE OF SLUDGE DIGESTION

Rudolfs' Summary.—Digestion is extremely slow at temperatures below 50° F. Raising the temperature a few degrees above 50° F. has comparatively little effect. Digestion time is materially decreased with higher temperatures. Maximum digestion takes place at about 80° F. Temperatures above 85° F. retard gas production.

The same quantities of organic material produce about the same volume of gas at all temperatures. Gas production depends upon the reaction of the medium. The average number of bacteria (on agar plates) in unadjusted sludge does not increase with the increase in temperature. The average numbers (on agar plates) in adjusted material decrease with the increase of temperature.

Exclusion of air induces liquefaction and increases the rate of solids reduction. This liquefaction can be changed by proper reaction and proper temperature to gasification. With the increased rate of digestion odors are intensified.

Baity's Statement.—At all temperatures it was observed that during the initial stages of the experiment there was a rather high rate of gas production accompanied by a sudden depression in pH values. This was caused by the bacterial decomposition of easily digested substances in solution, or colloidal state, with resultant acidic products. This gas contains a high percentage of CO_2 and low methane. Following this there is a

rather long period of slight activity during which alkaline products of this second stage of digestion cause a gradual increase in pH value. When pH 6.8 or 6.9 is reached gas production is accelerated, which at the higher temperature becomes almost violent, and the major part of the digestion takes place in a relatively short time. At this stage the gas contains its minimum content of CO_2 and maximum methane. The reaction during this period remains about 7.0, or neutrality. After this eruptive stage gas drops sharply and finally ceases entirely, and the pH reaches 7.4. The total time required for the digestion of this sludge at 10° C. (50° F.) is estimated at more than a year; the time required at 20° C. (68° F.) is about 130 days; at 25° C. (77° F.) 100 days are necessary; and at 38° C. (100° F.) about 85 days are required. This is for complete digestion.

A better idea of the probable time required at different temperatures for digesting this sludge (under natural conditions), sufficiently to draw onto drying beds, is given by the periods between the beginning of the experiment and the peaks of gas production. At 10° C. this is estimated at more than nine months; at 20° C. it was 70 days; at 25° C., about 54 days; and at 38° C. about 58 days were required.

With reference to gas production, it is notable that at all temperatures the total amount of gas produced during digestion was the same. The rates of production were different, as were the periods required for digestion, but the ultimate quantities of gas evolved were practically identical. From a number of experiments this total production was fairly well established at 420 cubic centimeters of gas at 0° C. and 760 millimeters pressure for each gram of dry organic solids[1] in the sludge used. If this can be expressed as a law, and there seems to be ample proof that it can, then the digestion of sludge and the influence of temperature in the process may be considered from another angle. At 20° C. the maximum observed rate of gas production was about 9 cubic centimeters per day per gram of organic matter. If that optimum condition could be maintained constantly then we should be able to digest this sludge in $^{420}/_{9}$ or 47 days. At 25° C. the maximum rate was 16 cubic centimeters per gram of organic material. By the same calculation used before, the

[1] For data on weight of organic solids per capita in sewage see p. 66 and for portion deposited as sludge see p. 218.

time required for complete digestion at 25° C. might be reduced to 36 days, if optimum conditions obtained. At 38° a maximum rate of 20 cubic centimeters per day per gram of organic solids was observed. So, with the most favorable pH reaction, we should be able to completely digest this quality of sludge in 21 days. From this study we may conclude that very little digestion can take place below 10° C.; that there is a critical point somewhere between 10° and 20° C. probably about 16° or 17° C. where a slight temperature difference causes a great change in the rate of digestion; and that the economical temperature to which sludge should be heated to hasten the process is probably not in excess of 25° C.

EFFECT OF RATE OF ADDITION OF FRESH SLUDGE

When the contents of a digestion tank are seeded with ripe sludge the digestion cycle requires a shorter period than when fresh sludge of a given concentration is unseeded. The New Jersey researches point to a ratio of 30 to 90 days at 70° F.

Rudolfs' Finding.—A proper balance of seeded material in a digestion tank, without lime adjustment, results when the daily addition of fresh sludge does not exceed 2 per cent on a dry basis of the ripe sludge in the tank. Then the alkaline material produced by ripe sludge is sufficient to overcome the acid material produced by the fresh solids. But if the reaction is controlled by lime the addition of fresh sludge may be increased to about 3½ per cent.

Baity's Conclusion.—In a plant where no attempt is made at artificial control of reaction, the rate of addition of fresh sludge should not be great enough to bring the pH value below 7.0. Further, in case lime is added for reaction adjustment. the rate of addition of fresh sludge is probably not a consideration, provided a sufficient number of organisms are present at all times to seed adequately the incoming fresh sludge. However, it is essential that the optimum reaction be carefully maintained. Too much lime may cause sterilization with cessation of gas production, and serious trouble may ensue. It should be added continuously and uniformly in such manner as to insure thorough mixing with the sludge.

In another communication to the authors, Rudolfs describes his recent experiences with the separate sludge digestion tanks at Plainfield. These data are given at the end of Chapter XXIV.

CHAPTER XXII

SINGLE-STORY SEPTIC TANKS

SYNOPSIS

1. Process.—This process as practically applied relates to ordinary flat-bottomed sedimentation tanks of the horizontal and continuous flow type. Instead of being frequently freed of deposits of solid matter, however, the tanks are designed and operated with the specific view of septicizing or digesting as much as possible of the deposited solids.

2. Double Function.—There are two distinct phases of this process. One relates to sewage clarification by sedimentation and the other to the digestion of solids, appearing as sludge and scum, so as to facilitate their disposal. The second phase ought not to be applied so as to interfere with the first in its preparation of sewage for discharge into watercourses or for filtration or other oxidizing treatment.

3. History.—Of French origin and early application for detached small plants, this process was popular in England after 1895 and its adoption spread rapidly on the continent and in America. Its popularity was checked by the competition of two-story tanks, particularly in Germany and America. In England its adoption in many cases practically meant only the omission of chemicals with the continued use of tanks as built for chemical precipitation plants. Gradually the removal of sludge from the English tanks became such that septicization was only an incident.

4. Extent of Use.—In 1911 there were about 200 municipal installations of septic tanks in use in the United States, the largest being at Baltimore and Columbus. The latter were converted to two-story septic tanks in 1917 and the former were later operated as plain sedimentation tanks in conjunction with separate sludge digestion. The process is still in favor for some installations in France and Scandinavia. In the United States it now is frequently adopted for institutions, and villages or

developments largely serving holiday visitors for a few weeks or months each year. It also serves small suburban districts, especially where plants are more or less temporary. In England it has no established status for large projects.

5. Efficiency.—When at its best this process approaches plain sedimentation in efficiency. It never lived up to its early reputation of being a complete purification process by itself, although it occasionally will yield a clear effluent in the case of new, small plants. It is only a question of time before gasification carries solid matters to the outlet. At some resorts these tanks have served several years without cleaning, but at city plants in daily service throughout the year they require fairly frequent cleaning. Otherwise the tanks will disgorge the retained sludge.

6. Advantages and Disadvantages.—There are some economies in certain cases in construction costs for single-story septic tanks. Bur ordinarily these advantages are offset by the solids disgorged at times in quantities in excess of those in the raw sewage. Besides this lack of efficiency, they frequently have given trouble from odors from the released gases. Another odor complication has been due to the necessity of disposing of sludge which has not been sufficiently digested. Furthermore, the effluents have sometimes shown the effects of anaerobic decomposition so that they have become over-septicized and difficult to oxidize in following treatments.

7. Tanks in Rotation.—From intermittent operation, to permit digestion of sludge before cleaning, in a more or less haphazard way there developed the custom of using tanks in rotation. Thus, if there were four or five tanks, one would be used as a settling tank until the effluent showed solids sufficient to elog filters or nozzles. Then it would be put out of service and allowed to stand to aid sludge digestion. Each tank was so used in rotation. Sludge would be removed only when the given tank had to be put in service again as a settling tank. Where plants were suitably arranged, 4 or 5 months or so would thus be provided for sludge digestion. This method was used at the old Plainfield, N. J. plant (abandoned in 1916), Morristown, N. J., Washington, Pa., and other places, particularly near Chicago. In August, 1918, this method of operating Doten tanks at army posts was recommended in a joint report by Metcalf & Eddy and by Fuller & McClintock. The Armistice came before tank enlargements were provided.

8. Present Status.—While larger and better designed tanks of this type, if used in rotation, would give good results for large projects, there have been few installations during the past dozen years. This is explained by the development of two-story tanks and the use of plain sedimentation tanks, the sludge from which is disposed of with the aid of other arrangements. Single-story tanks, however, have economical aspects commending their consideration for fairly small projects, particularly when the load is light for some months each year.

HISTORICAL DEVELOPMENT

About 1895 Cameron, an English engineer, developed the process of septic tank treatment and patented it. Numerous English chemical precipitation plants were operated on this basis. In 1911 there were over 200 such tanks in operation in the United States. Today, in America and also in Germany, single-story tanks have been largely superseded by two-story septic tanks for large installations. In England sewage tanks are cleaned with sufficient frequency so that in general they act as plain sedimentation rather than as the septic tanks of earlier years. In America, the usefulness of the single-story tank is in general restricted to small municipal or institutional plants; although plants consisting of several parallel single-story tanks used in rotation may occupy a somewhat wider field.

In the old single-story septic tanks of the City of Plainfield, N. J., in service from 1901 to 1916, Lanphear[1] found a reduction in suspended solids from about 150 parts per million to less than 50 parts per million during the first month or so after a freshly cleaned tank was put into service; but after this time septic action caused sludge and scum to appear in the effluent, even though the tanks were fairly well baffled. It became difficult to keep the suspended solids in the effluent below an average of 70 parts per million. Better effluents were obtained by using two of the four units at a time, and then using the other two while digestion took place in the first two.

The plain settling tanks at the Baltimore Sewage Works were used at one time in a manner approaching that of single-story septic tanks. Since about 1920, however, the tanks have been used primarily for plain settling, and are cleaned every 6 to 10 days. Scum formation occurs within several days and a

[1] Eng. News-Record, Jan. 13, 1912.

considerable amount of septic action starts within a few days in the summer. These tanks will be superseded shortly by plain settling tanks with provisions for continuous removal of sludge. At present the cleaning of the tanks is attended with considerable odors due to the decomposition of the sludge.

TANK CHARACTERISTICS

Capacity.—Single-story septic tanks as now built in America for small communities ordinarily have a capacity approximating 24 hours dry weather flow. Capacities of 8 to 12 hours, which were is use some 15 years ago, frequently led to the discharge of gas-lifted solids in the effluent or to the necessity of removing the sludge before it was fully digested.

Covers.—Many tanks are uncovered, but covers are considered preferable, largely to lessen the discharge of odorous gases and in large units to prevent agitation by wind action. Where the sewage solids are undigested, a thick scum may cover the liquid due to the gas lifting portions of the sewage solids. High grease content adds to scum formation which may become so thick that, floating above the water line, it does not digest, thus adding to the burden of digestion of solids in preparation for removal in an inodorous condition.

Over-septicization.—In tanks which are very large as to detention period or in which cleaning has been long deferred there have been cases where filtration processes have not worked well with the tank effluent.

Sludge Unloading.—After a septic tank has been in service from about 4 to 6 weeks, depending upon temperature, the digesting sludge is gas lifted in large quantities. As the bubbles break at the surface, or beneath the scum, much of the sludge falls back to the bottom. Thus there is a constant vertical circulation of solids which have already been deposited, some moving upward and then downward and some remaining attached to the surface scum. Eventually this action approaches the outlet end and solids appear in the effluent. Unless well baffled this may mean that the tank becomes inefficient as a settling tank long before the solids are suitably digested. Continued use may cause the disgorging of sludge so that in the effluent the quantity of suspended solids is greater than in the influent.

One reason why the single-story type of tank has lost favor is the presence of such solids in the effluent, resulting in formation

of sludge banks in streams receiving the effluent, and in surface clogging of filters and clogging of filter nozzles. The single-story septic tanks put into service at Columbus in 1908 were converted a few years later into two-story tanks partly for this reason. The conversion of the single-story tank at Reading, Pa., into a two-story tank has been recommended for years by engineers.

Kimberly in his Special Report to the Ohio State Board of Health, 1908, gives interesting data showing the striking extent of the unloading of sludge. These figures are shown in Table 53.

TABLE 53.—SUSPENDED MATTER IN EFFLUENTS OF REPRESENTATIVE OHIO SEPTIC TANKS

Place	Date	Rate of sewage flow, gallons in 24 hours	Tankage, hours' flow	Suspended matter: Parts per million, Crude sewage	Suspended matter: Parts per million, Septic effluent	Suspended matter: Percentage removal
Ashland	July 11–12, 1906	150,000	6.3	50	70	−40
Ashland	April 24–25, 1907	375,000	2.5	70	50	29
East Cleveland	June 26–27, 1906	365,000	11.2	210	400	−91
East Cleveland	July 11–12, 1907	390,000	10.4	110	180	−64
Geneva	June 21–22, 1906	181,000	5.2	60	65	− 8
Geneva	June 24–25, 1907	204,000	4.6	90	150	−67
Kenton, N. Dist.	October 5, 1906	18,000	24	220	180	18
Kenton, N. Dist.	July 2–3, 1907	17,000	27	70	120	−72
Lakewood	June 12–14, 1906	395,000	18	45	45	0
Lakewood	June 12–14, 1907	1,150,000	6.2	100	140	−40
Mansfield	May 28–29, 1907	1,058,000	23	75	110	−47
Marion	May 23–25, 1906	415,000	24	150	85	43
Marion	Nov. 8–9, 1906	370,000	27	90	140	−55
Marion	April 9–11, 1907	578,000	17	40	45	−12
Sandusky, S. and S. Home	June 5–6, 1906	155,000	17	95	90	5
Sandusky, S. and S. Home	May 8–9, 1907	174,000	15	95	90	5

NOTE.—Suspended matter to nearest 5 parts below 100 and to nearest 10 parts above 100.

Baffles and Connections.—Originally it was thought necessary to have the inlets and outlets trapped beneath the sewage surface and to exclude air and light by a tight cover. Increasing knowledge of biochemistry soon showed it to be unnecessary to provide tight covers. The trapping of pipe connections was to avoid disturbing the bottom sludge or the top scum. Operating experiences on a large scale soon showed the necessity of using baffles or multiple inlets to distribute the flow throughout the

width of the tank and particularly to arrange baffles to prevent solids from appearing in the effluent. During the war, tanks designed by Major Doten were adopted for use at the training camps (see Fig. 32). The floors sloped to several sumps for sludge removal. They were well baffled, the outlet baffles being especially worthy of commendation.

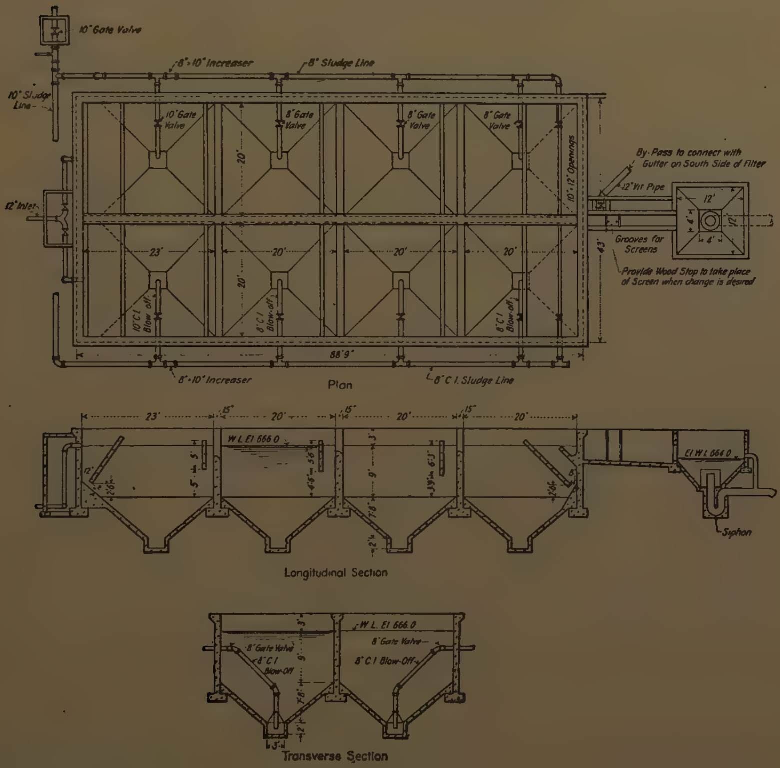


FIG. 32.—Doten tank.

Tanks in Rotation.—When septic tanks are cleaned shortly after being put out of service, the sludge removed will contain portions of undigested solids. This led in many places to the custom of allowing tanks to stand for a period after going out of service, in order to promote digestion of sludge and scum recently separated from the sewage.

An example of the careful and successful use of the intermittent method of operation of septic tanks, applied to tanks

used in rotation, is at the Washington, Pa., sewage works. The practice of operating the tanks as sedimentation tanks and then, after being put out of service, as sludge digestion tanks was started in 1912 and has been followed since. There have been no difficulties with odors.

There are four tanks at Washington, Pa., each 88½ feet long, 20 feet wide and 9 feet effective depth. The estimated flow of sewage averages 2 million gallons per day, all of which flows through one tank. For the past 2 years the tanks have been in service from 35 to 56 days each. The period of digestion has ranged from 3 to 6½ months. The sludge was well digested and dried easily on beds.

Sludge Digestion.—Generally speaking, sludge was not uniformly humified as sent from single-story septic tanks to sludge beds. Most tanks ordinarily gave fair results, but occasionally sludge or scum in a bad-smelling condition had to be removed. The liquid contents of the tanks added to the burden of sludge and scum disposal, by increasing the volume actually to be dealt with up to 3 or even 5 cubic yards per million gallons of sewage treated. No doubt these shortcomings would have been corrected by more suitable and expensive design of tanks, had not competition from other types pushed the single-story septic tank into the background.

Cleaning.—Tanks with flat bottoms have not been very satisfactory as to cleaning operations. As a rule the solids may be removed only with the aid of pushers to force the solids to the outlet pipes. Flushing facilities with sewage or water under pressure may prove satisfactory. With masonry covers near the flow line it is important to ventilate the tanks well before sending men into them.

Odor Question.—While many septic tanks have given reasonable service as to freedom from complaint of odors, particularly if well isolated, there are others, mostly too small, which have given trouble at times from undigested sludge and scum or from gas released in whiffs during humid weather, or both.

Practicability.—More single-story septic tanks have been built for small residential communities, institutions, summer resorts, and for industrial plants than are generally realized by American engineers; but for municipal service their usefulness is limited to places where quicksand, rock or particularly ground water make it expensive or difficult to build the deeper two-story

tanks. When single-story tanks are built of ample size so as to provide for a period of detention approaching 24 hours, their availability is still further restricted by cost. Small communities may not need so great a capacity, but generally speaking small tanks have been unsatisfactory, as shown by the release at intervals of large quantities of gas-lifted sludge. Digestion also is often incomplete, due to the necessity for frequent removal of the sludge in order to insure adequate sedimentation space.

CHAPTER XXIII

TWO-STORY SEPTIC TANKS

SYNOPSIS

1. Description.—A two-story septic tank comprises an upper or sedimentation compartment, and a lower or digestion compartment, separated by sloping walls or partitions having openings or slots at the bottom through which solids that have settled in the upper compartment continuously drop into the lower. In most cases the slot is trapped so that particles which once enter the lower compartment cannot return. The upper chamber is preferably made as shallow and the lower as deep as practicable. Such tanks are called Emscher or Imhoff tanks.

2. Separate Phases.—Compared with single-story tanks the outstanding feature is that settling and sludge digestion are quite separate and can proceed continuously. The effluent is normally unaffected by either gas-lifted sludge or by liquid that has become septicized. Due to a shorter detention period, the freshness of the sewage is far less affected in two-story than in one-story tanks. With well arranged two-story tanks it is not necessary to operate them intermittently or in rotation in order to digest the sludge.

3. Sludge Digestion.—In about 6 months or less after beginning operation, the sludge ordinarily becomes digested, and thereafter portions of it are drawn upon drying beds at intervals, always leaving some of the digested sludge in the tank. Gas formation always keeps the digesting sludge mixed with the incoming, fresh sludge. The gas evolved may be collected to prevent odors, and if so collected may be utilized as fuel or in other ways.

4. Extent of Use.—In the Emscher and Ruhr districts and in some other localities in Germany since 1907, and in the United States since 1911, this type of tank has been generally adopted for sedimentation purposes, to clarify sewage prior to disposal by dilution or prior to treatment by coarse-grained filters. In England it is little used.

5. Capacity.—The sedimentation chambers ordinarily have a detention period of about 1½ to 2 hours based on the average rate of flow, with velocities less than 1 inch per second. The digestion chamber should have a capacity of at least 2 cubic feet per capita of connected population, for domestic sewage in the northern part of this country; with 50 per cent more for combined sewage; and with 50 per cent less for each type of sewage in the southern than in the northern states.

6. Efficiency.—Two-story septic tanks will remove from 50 to 70 per cent of the suspended solids in the incoming sewage; from 90 to 95 per cent of the settleable solids; and from 30 to 35 per cent of the total organic matter. There is incidentally a reduction of bacteria, although this is not the aim of the process. They will produce, under suitable conditions, a well humified, inodorous sludge, filled with entrained gas and containing about 85 to 95 per cent of water, which will readily dry on drying beds.

7. Disadvantages.—In some plants, in the past, foaming during digestion has occurred at times to such an extent as to cause the floating sludge to overflow into the sedimentation chamber. This has also resulted in the necessity for withdrawing undigested sludge, with attendant odors. Gases released during digestion have also caused odors to some extent. With digestion chambers of ample capacity and means provided for collection of gas, these difficulties may be overcome. These deep tanks are also expensive to build at some locations where foundations are difficult. In England they have been objected to partly on the score of cost and partly because of uncertainty as to their suitability for handling storm flows up to three or even six times dry weather flow.

8. Advantages.—Two-story septic tanks, as compared with single-story tanks, permit higher velocities of flow without occasioning bottom scour, and prevent contamination of the effluent by gas-lifted sludge particles. In many cases they have produced thoroughly digested sludge, without occurrence of extensive odors. Where means are provided for collection of the gases evolved and for the submergence of scum, by devices described in Chapter XXV, odors and sludge overflows from the gas vents into the settling compartments are avoided. This is a feature of current practice as in the Essen district in Germany and at Decatur, Ill. The tendency in modern practice, likewise, is toward shorter periods for settling in shallow upper

compartments. This fact, combined with the design features as to gas collection and scum overflow, prevents odors at sprinkler nozzles.

9. Present Status.—Two-story tanks have ordinarily proved to be much more satisfactory than single-story septic tanks. Present practice as compared with earlier designs has resulted in better performance and permits thoroughly satisfactory results to be obtained. They are now in competition with plain sedimentation tanks and separate sludge digestion. Present evidence does not warrant detailed discussion of relative costs. Each problem should be studied on its own merits.

HISTORY

These tanks had their origin scientifically at the Lawrence Experiment Station about 1899. They were first developed on a working basis by Travis at Hampton, England, in 1903, where a portion of the sewage was conveyed through the lower compartment to wash out excessive quantities of enzymes. Imhoff increased the size of the lower compartment, but eliminated the flow of sewage through it, and installed many plants in the Emscher district, near Essen, beginning in 1907.

In 1891, before the nature of septic action was understood, a sedimentation tank was patented in England, in which baffles or sloping partitions were provided to form a separate sludge space below them. Later Travis made use of similar sloping partitions or baffles in his two-story hydrolytic tank at Hampton, 1903. This was the first practical step, as a result of the studies made at Lawrence, Mass., to avail of septicization in a compartment separated from the sedimentation chamber. Four-fifths or more of the sewage was passed through the sedimentation compartment, with the solids settling automatically into the digestion chamber below. The remainder passed through the digestion chamber with the idea of improving the conditions for hydrolysis or septicization.

Associated with the Hampton tanks has been the theory of de-solution, meaning the removal of much of the colloidal matter and non-settling suspended solids by physical action alone. To utilize this action, vertical splines or slats called colloiders were hung in the sedimentation chambers of the Hampton tanks, to the surfaces of which the finely divided suspended matters and

colloidal substances adhered. So far as known the practical value of these slats has never been determined.

Three Hampton tank installations were made in England, but only one or two in America.. So far as known the sludge was in no case adequately digested and was removed at fairly frequent intervals and disposed of like undigested sludge. They have been used recently at Munich and Zurich in a modified form as settling tanks, from the lower compartment of which the sludge has been removed at frequent intervals before septicization, as stated in Chapter XXII.

Emscher or Imhoff Tanks.—In the Emscher district of western Germany, construction of an experimental Hampton tank was begun in 1905; but before its completion a tank was evolved in which the sewage in the sedimentation chamber was kept as fresh as possible by preventing the sewage in the sedimentation chamber from coming in contact with the contents of the lower chamber. Since that time this type of tank has been most carefully studied in operation in the Emscher and Ruhr districts by Imhoff and his associates. Credit should also be given to the early work of Clark at Lawrence and of Travis. The credit for early recognition of the merit of this two-story tank for the solution of American problems belongs to Hering.

The Imhoff tank was first placed in regular operation at Recklinghausen, Germany, in February 1907, serving a population of about 30,000. Its early history in the Emscher district is well outlined in the Journal of the Association of Engineering Societies, Vol. XLVII, July, 1911.

In America the process was soon afterward studied at Philadelphia, Pa., Chicago, Ill., Columbus, Ohio, and Worcester, Mass. Among the earliest plants built in this country are those at Madison-Chatham, N. J.; Pennypack Creek, Philadelphia; Atlanta, Ga.; Batavia, N. Y.; Chambersburg, Pa.; Winters, Calif.; Rome, N. Y.; and Winchester, Ky.

The number of installations of Imhoff tanks increased very rapidly and during the past 10 years American installations have many times exceeded, both in number and size, those made in Germany. There are now perhaps nearly a thousand municipalities and institutions making use of them, either alone or as preliminary to other treatment. Among the large plants in this country may be mentioned those at Rochester, N. Y.; Akron, Ohio; Albany, N. Y.; Chicago (Calumet); Schnectady, N. Y.;

Cleveland (West Side); Dallas and Fort Worth, Texas; Philadelphia (North East); and Worcester, Mass.

CONSTRUCTION FEATURES

Types.—Imhoff tanks have been built of three distinct types, known as radial-flow tanks, horizontal-flow tanks with rectangular digestion chambers, and horizontal-flow tanks with circular digestion chambers. The first of these types is often used for small installations. For large installations the second type is used in this country and the third in Germany, (see Fig. 33)

FIG. 33.—Imhoff tanks, Essen-Rellinghausen, Germany.

American and German Tanks.—Imhoff (Fortschritte der Abwasserreiningung, 1925) mentions as distinguishing features of American tanks a rectangular foundation plan for large installations; provision of connecting openings through the walls separating the several sections of the sludge compartment, and the provision of gas-vent openings for each separate section. He also mentions the following characteristic features as having proved satisfactory in Germany; the installation of gas collectors for utilization of the gases from the sludge; the construction of the digestion chamber with practically no exposed surface, in order to

avoid scum formation and prevent odors; the greatest practicable depth of digestion space below the slots, and the greatest reasonable area of settling chamber, with depths not more than 3 to 6 feet.

Preliminary Devices.—Coarse bar screens, about 2 inches in the clear, usually precede Imhoff tanks. For the flow from combined sewers, grit chambers should also be used. In a few instances, as at Plainfield and Rochester, fine screens have been used to reduce the amount of coarse and floating matter and thus reduce scum formation.

Sedimentation Chamber.—Earlier plants in this country had an average period of detention in the sedimentation chamber of 2.5 to 3.0 hours or more. Later practice has reduced this time to about 1.0 to 1.5 hours, since about 95 per cent of the settleable solids are removed in that time. In the Rochester tanks the average time is only 1.1 hours, which corresponds roughly to current practice in Germany.

A shallow sedimentation chamber is more efficient, other things being equal, than a deeper one, as that portion below a depth of 6 or 7 feet is apparently not effective. But the walls of the chamber should be steep, so that the solids may settle freely to the slots. Slopes of at least 5 vertical to 4 horizontal are desirable; but very steep slopes would increase the depth without increasing the useful capacity.

In rectangular tanks the ratio of length to width is limited by velocity requirements, and by ability to distribute the sewage over the cross-sectional area. The velocity, based on maximum sewage flow and full displacement in a suitably designed cross-section, should never exceed 2 inches per second according to Imhoff or ½ inch according to American views as well as earlier German experience. These indicate the critical velocity to be about ⅓ inch per second or 100 feet per hour, whereas Imhoff states but little is gained by reducing the average velocity below one inch per second. In radial flow tanks, the upward velocity from beneath the annular baffle should not exceed 0.02 inch per second. If the sewage could be distributed uniformly through the cross-section of rectangular sedimentation chambers, the length could be very short. Greater lengths and higher velocities improve the distribution in the cross-section. A length of at least twice the breadth is desirable, and three times is perhaps most common in larger installations.

The inlet and outlet should be constructed alike, so that the flow may be reversed, as explained below. The outlet should preferably be a skimming weir. For the inlet, a weir, while theoretically advantageous in keeping the sewage distributed, may cause stranding of the larger solids present in the incoming sewage. To prevent this, a large opening may be provided at the middle of the weir, with a gate to be removed at the inlet end and to be kept in place at the outlet. Such an arrangement creates a slight tendency to short-circuit the chamber, and baffles or other devices may be introduced to remedy this; but frequently the only baffle is the scum board.

In large installations consisting of several tank units side by side, operated in parallel and served by the same inlet and outlet channel, means must be provided to pass the same amount of sewage through each of the several tanks. It is also important that there be no opportunity for any of the sewage to pass downward through the slots and up again into the sedimentation chamber at some other place, thus carrying liquid from the digestion chamber out with the effluent.

Scum boards should be provided for the retention of floating matters. Inlet, outlet and bypass channels should be such as to have scouring velocities and to be easily cleaned. All surfaces should be made as smooth as practicable.

Digestion Chamber.—Digestion chambers have frequently been made too small in this country. The required volume depends upon the number of people contributing sewage, the temperature in the chamber and the length of the cold season when sludge cannot be drawn. Greater volume is necessary with combined sewage, and where industrial wastes or large amounts of fat are present.

As stated, about 2 cubic feet per capita of contributing population are needed for domestic sewage in the northern states, and about 3 cubic feet for combined sewage. For warm climates half of the above may be sufficient. In the Ruhr district in Germany, where the average annual temperature is very little higher than in New York, a volume of rather less than 1 cubic foot per capita has been found satisfactory, although this may be due to the partial digestion of the solids in cesspools before reaching the tanks and to the relatively weak character of the raw sewage, as well as a more favorable distribution of rainfall and freezing weather than in America. Where the digestion

chamber is to receive, in addition to the ordinary settleable solids, excess activated sludge, the capacities must necessarily be increased. This is proposed for the West Side tanks which are to receive activated sludge from the North Side plant at Chicago. This is further discussed in Chapter XXXIX.

In Germany and in the earlier tanks constructed in America, the plan dimensions of the digestion chamber are smaller than those of the upper story, resulting in a division of the digestion chamber into several separate units not in contact with each other. In the later American designs for rectangular tanks, the lower and upper stories have practically the same plan dimensions.

The depth of the digestion chamber is sometimes great, as is customary in Germany, where the separate units are frequently sunk as wells. Depth is expensive, especially in the wet excavation usually encountered, so that in America continuous chambers of larger area and lesser depth are customary. At Schenectady, N. Y., the maximum depth below the slots is 6 feet 1 inch; at Plainfield, N. J., 8 feet 9 inches; at Fitchburg, Mass., 11 feet no inches; but at Rochester, N. Y., it is 22 feet 6 inches. The sludge formed in shallow chambers is generally less dense, and therefore shallow chambers should have somewhat greater capacity. The entire depth below the slots is not available for sludge digestion, due to non-uniform deposit of the incoming sludge and presence of uncomminuted solids. In Eddy's paper on "Imhoff Tanks: Reasons for Differences in Behavior" (Trans. Am. Soc. C. E., Vol. 88, p. 465), he assumed, for purposes of discussion, that the net effective depth was that below a so-called "neutral zone" of 18 inches below the slots.

In order that the depth and character of the sludge deposited along the digestion chamber may be uniform, the direction of flow of the sewage, in some plants, is reversed about twice a month. It is furthermore necessary to limit the length of the tanks, since the greater part of the solids, including the coarser particles, settles soon after the sewage enters the sedimentation chamber. Not more than three separate longitudinal compartments in the digestion chamber are advisable, and these should be joined by large openings. From the standpoint of sludge distribution the length should be not more than about three times the width.

The digestion chamber should be provided with one or more sumps. A floor slope of 1 vertical to 2 horizontal is suffi-

cient, although 1 to $1\frac{1}{2}$ is often used. The Akron tanks and the design for the West Side tanks at Chicago have no sumps but provide continuous valleys.

To aid the flow of accumulated solids, particularly grit from combined sewage, toward the sump when sludge is withdrawn, rings of perforated pipe are frequently provided on the floor around the sump, through which water or sewage under pressure may be introduced. This procedure may also aid in digesting the sludge, or in liberating entrained gases which might cause the sludge to float. For these purposes, however, a portable pressure pump is generally satisfactory, and in fact preferred by some. Small piping and any other fittings or devices in the digestion chamber should be of lead or some other non-corrodible material, since galvanized or wrought iron is rapidly destroyed.

For removal of the digested sludge a cast-iron riser pipe is placed above each sump, provided with a bell mouth at the bottom and extending at least as high as the sewage level. The riser is open at the top so that it may be rodded or flushed out if necessary. Gated branches extending from each riser at least 5 feet or more below the sewage level carry away the sludge, which is somewhat viscous and requires a hydraulic grade of 1 in 30, or at least 1 in 50, in the discharge pipe or channel. Where the unbalanced hydraulic head is insufficient, pneumatic ejectors, to which the sludge flows by gravity from the tanks, are frequently used. Suction, or the use of centrifugal pumps, tends to separate the entrained gases from the sludge and makes its drying more difficult.

During decomposition of the sludge, gases are formed in large volume. To permit escape to the atmosphere of the gases which do not remain entrained in the sludge, it has been customary to extend portions of the digestion chamber to the surface alongside the sedimentation chamber. The area of such openings or shafts has been about 15 to 25 per cent of the tank area. The volume above the sludge surface, ordinarily called the scum space, has been from $\frac{1}{2}$ to $1\frac{1}{2}$ cubic feet per capita.

Gas Collection.—Lately in Germany tanks have been built or changed so that none of the digestion chamber is open at the surface. The gas is collected through small individual gas shafts. The scum is kept from exposure to the air and in submergence, where it will more readily decompose, will not emit odors and will not overflow into the settling compartment. The

gas may be utilized if desired. The plant at New Castle, Pa., is being so built and gas collectors have been installed on some units of the tanks at Decatur, Ill. The collection and utilization of gas are treated in Chapter XXV.

SLUDGE DIGESTION

Ripening.—When tanks are first put into operation, or when they lose their digestive ability, the sludge is said to be "ripening." The length of this period is uncertain. "Seeding" with ripened sludge has not always been as helpful as anticipated. The first sludge may be fresh, and occasionally acid decomposition may occur, in which case the sludge will decompose slowly, will not dry easily, will have an objectional odor and will tend to rise as a body to the surface.

Digestion.—After completion of the ripening period, sludge digestion proceeds without objectionable odors, and the sludge becomes black and alkaline. During digestion, gases of decomposition cause particles of sludge to rise, give up their gas content, and then sink. Thorough mixing thus takes place, so that fresh particles entering from the sedimentation chamber become mixed and inoculated with digesting sludge.

Acid Foaming.—Acid foaming has at times been very bothersome. Raising the gas vents 5 or 10 feet does not stop it. Jetting with pressure water, stirring, and liming may help. Aggravated cases are not cured by putting a tank out of service for several months. When tanks are too full sludge removal aids, but sometimes most of the sludge is floated by gas, and must be removed from the gas vents; otherwise the scum space may be completely filled to below the slot level so that decomposing matter may enter the settling compartment through the slots as well as by overflowing. The remedy for this condition lies in making the digestion space sufficiently large to allow ample time for digestion and in proper regulation of reaction of decomposing sludge. These matters are further discussed in Chapters XXI, XXIV, and XXV.

Scum.—Upon the surface of uncovered digestion chambers or gas vents a layer of scum forms. This should be distinguished from the viscous, floating or foaming sludge described above. The scum should be broken up by beating it with paddles or by

jetting it with a hose stream so that as much of it as possible will sink and digest and the remainder should be removed. In tanks where there is no exposed scum area, as already described, digestion of the submerged scum takes place to a reasonable extent.

OPERATION

In operation it is necessary to keep the channels and sedimentation chambers clean. The flow of sewage should be reversed about once in 2 weeks. Sludge should be withdrawn from each compartment every 2 to 6 weeks, if the weather is suitable for drying. Relatively small quantities should be drawn from each compartment in succession. Withdrawal should be stopped whenever partly digested sludge appears, as indicated by odor and appearance. At least 1 month's deposit of sludge should always be retained in the tank, and the sludge level should preferably be kept about 3 feet below the slots.

RESULTS OF OPERATION

Two-story septic tanks, well designed and operated, should produce, without giving rise to objectionable odors and conditions, a well clarified effluent and a sludge reduced to practically humus matter. However, some installations of Imhoff tanks in this country have at times proved troublesome to operate, and satisfactory results in these cases have been attained only through much care and labor. Although the causes of this are even now not entirely understood, much has been learned, and the successful design and operation of Imhoff tanks in the future should be much more readily accomplished. For a discussion of this subject reference is made to a paper by Eddy on "Imhoff Tanks—Reasons for Differences in Behavior," and the discussions thereon, in Trans. Am. Soc. C. E., 1925, Vol. 88, p. 465.

When functioning properly, the two-story septic tank will clarify the sewage up to the limits to which plain sedimentation may be advantageously carried. Automatic removal of deposits by gravity into the lower compartment minimizes the effect of scouring velocities, and practically no gas-lifted particles of sludge are found in the effluent. But unless scum and fat accumulations upon the walls and sloping bottoms of the sedimentation

chamber are promptly and thoroughly removed, the effluent may contain suspended matters in process of decomposition.

Bacterially, this process is not of importance, although bacterial removal frequently approximates that of suspended matter, since the bacterial content of the effluent is not affected by the intensive growths of bacteria in the lower compartment. (See Gaub's[1] work at Plainfield.)

The stability of the effluent as a result of clarification is improved, being about 25 to 35 per cent greater than that of the raw sewage. In the relatively small sedimentation compartment dissolved oxygen is not as much reduced as it would be in large single-story tanks in which septicization is taking place.

The main feature of this tank is the sludge treatment, by which, under reasonably favorable circumstances, the putrescible matter becomes liquefied or gasified in the digestion compartment without offensive odors, and a product is obtained which can be readily dried and finally returned to land as practically humus matter.

DISCUSSION OF TWO-STORY SEPTIC TANKS

New Castle Design.—At New Castle, Pa., the authors put under construction in 1925 a two-story Imhoff tank to serve a future population of 60,000 and to treat an average flow from separate sewers of 9 million gallons daily. Sections of this tank are shown in Fig. 34. A notable feature of this tank is that arrangements have been made for collection of the gases, in order to minimize possible odors. Except for the shafts where gas collectors are placed, the entire digestion chamber is covered by the floor or walls of the sedimentation compartment. The scum will thus be kept submerged and not permitted to dry, thus aiding in its digestion.

The sedimentation period is 1.5 hours, and the sludge capacity below a plane 18 inches beneath the slots is 2 cubic feet per capita. The maximum depth of the tank below the sewage surface is about 27 feet, and the depth of the sedimentation compartment varies from 3½ to 9½ feet. The length is 74 feet. Swinging gates are provided to deflect the right amount of sewage to each of the six units. The flow is reversible; the inlet is through gated openings and the outlet over weirs.

[1] Bulletin 394, 1924. N. J. Agricultural Experiment Station.

Scum boards are provided near each end. Comparing this design with that of Eddy for Fitchburg (see Fig. 35), the principal differences are the relatively smaller and shallower sedimentation chambers, and the gas collectors.

Plainfield.—The Imhoff tank at Plainfield, N. J., designed by the authors, was one of the earlier two-story tanks built in this

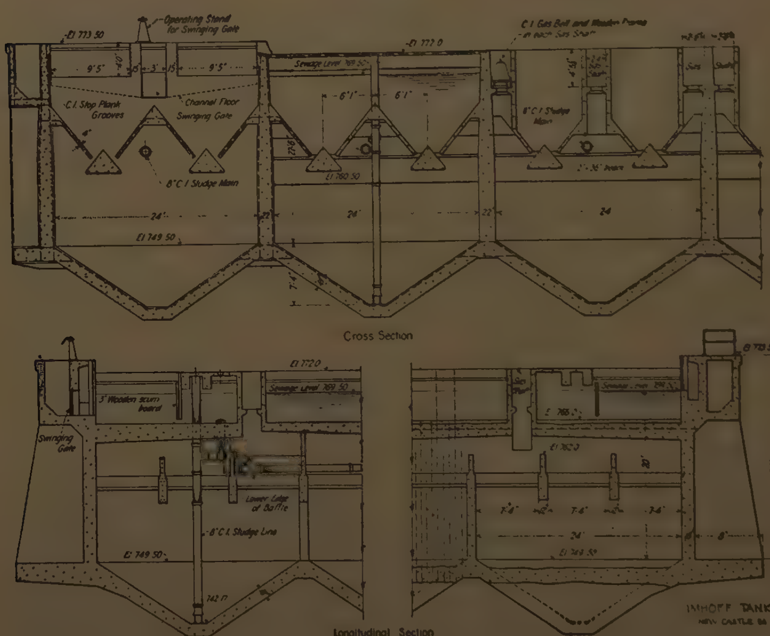


FIG. 34.—Imhoff tank, New Castle, Pa.

country. It comprises six parallel units, each being about 64 feet long and 25 feet wide, and having five digestion compartments connected by small openings. The maximum depth below the sewage level is about 20 feet, and the depth of the sedimentation compartment is from 6 to 11 feet. The tank was designed for 40,000 people, or 4 million gallons of sewage daily. The average period of detention of sewage is about 3 hours and the sludge capacity below the slots about 1.2 cubic feet per capita.

The operation of this tank has been troublesome, due to excessive foaming, resulting at times in overflow of floating sludge into the sedimentation compartments and also in the production of odors. Much labor has been required to remove the floating

solids. The deposit of sludge was not uniform in the five compartments, much of it being deposited in the end chambers. To remedy these conditions, fine screens were installed in order to reduce scum formation, and the sewage was run at higher velocity through three of the six compartments at a time in order better to distribute the sludge. These measures have not been entirely successful, however, as foaming still persists to some extent.

The Plainfield plant is an interesting example for discussion for several reasons. In the first place, it is one of the four plants described by Eddy in his paper before the American Society of Civil Engineers[1] which with the discussion thereon makes the most comprehensive and enlightening account in existence as to the behavior of two-story tanks. Secondly, the Plainfield plant has been studied with unusual care by Downes, Supervising Engineer, and by the staff of the New Jersey Experiment Station under Rudolfs. These men have made various investigations as to the scientific basis for sewage purification processes in practice. Thirdly, it affords an opportunity for the authors, as designers of this plant, to state changing viewpoints between 1913–14 when the Plainfield plant was designed and those which have resulted from operating experiences since that date in America and also in Germany as observed by Imhoff.

Table 54[2] summarizes essential data of four leading American Imhoff tanks from which operating experiences have been obtained.

Eddy concludes that the foaming troubles at Plainfield with release at times of bad-smelling gases, and that the incompleteness of the sludge digestion at Plainfield and at Schenectady are due to unfavorable conditions at these plants, as follows:

(*a*) Shallowness of tanks.

(*b*) Inadequate digestion compartments.

(*c*) Impossibility of uniform distribution of sludge throughout digestion compartments.

(*d*) Large number of digestion compartments, making it impracticable to determine volume and density of sludge in them and difficult to cope with sludge and scum problems.

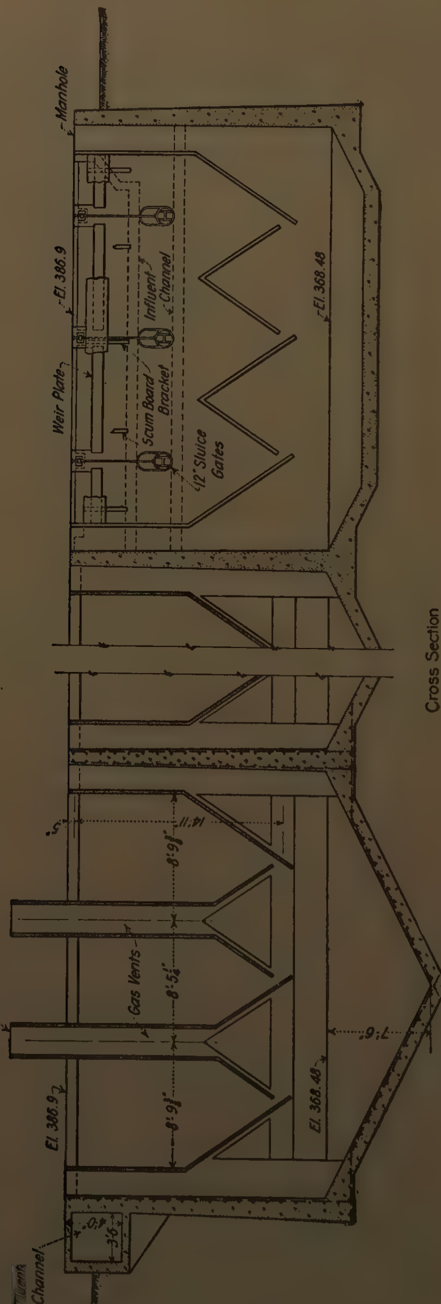
(*e*) Absence of heavy solids from street washings.

(*f*) Relatively large proportions of insoluble soaps.

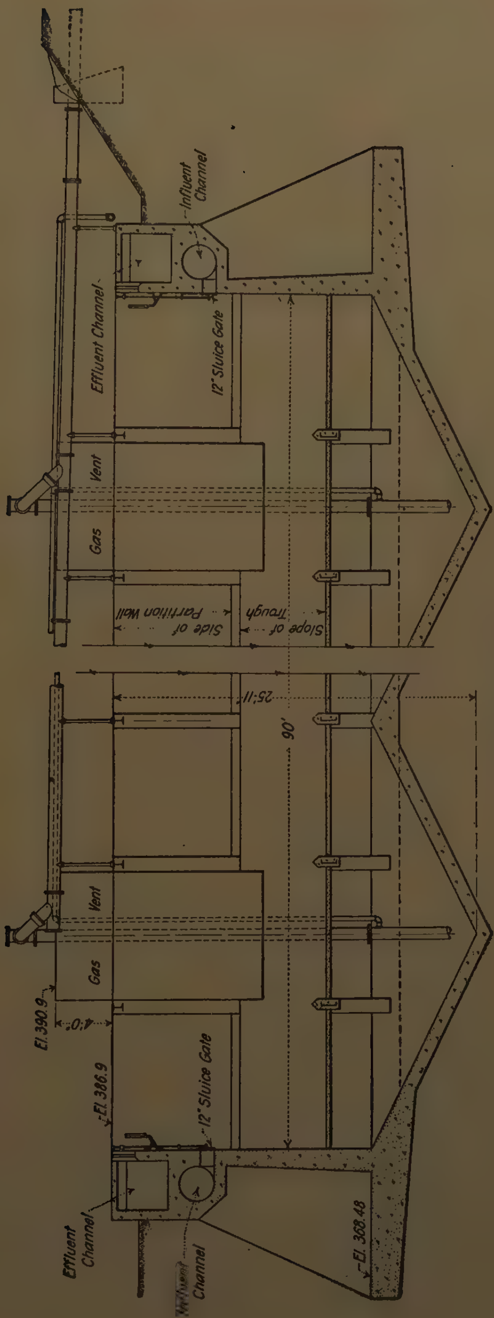
The history of conditions as above set forth and comments of the designers are recorded under several headings as follows:

[1] Trans. Am. Soc. C. E., Vol. 88, 1925, p. 465.

[2] Trans. Am. Soc. C. E., Vol. 88, 1925, p. 492, Table 15.



Cross Section



Longitudinal Section

FIG. 35.—Imhoff tank, Fitchburg, Mass

TABLE 54.—SUMMARY OF ESSENTIAL DATA ON IMHOFF TANKS

Item	Schenectady, N. Y.	Plainfield, N. J.	Fitchburg, Mass.	Rochester, N. Y.
Tributary population (1922)	65,000	40,000	38,000	260,000
Character of sewage:				
Flow, in million gallons per day	6	3.4	3.4	32
Separate or combined sewers	Separate	Separate	Combined	Combined
Strength (suspended solids), in parts per million	163	166	219	163
Freshness	Fresh uncomminuted	Stale	Fresh	Stale
Industrial wastes	Practically none	Practically none	Small amount	Small amount
Hardness of water supply, in parts per million	130	88	10	65
Temperature, in degrees, Fahrenheit.	Av. (1922) 56.1 Max. 64.7	46–70 48–74	No data	Av. 54
Preliminary treatment:				
Screening	Coarse rack	Fine screens, ¹⁄₁₆-in. slot	Coarse racks	Fine screens, ⅛-in. slots
Grit chambers	None	None	Yes	Yes
Imhoff tanks:				
Sedimentation period, in hours	3.3	3.4	6.4	1.1
Depth of tanks:				
Total maximum water depth	13 ft. 9 in.	19 ft. 9 in.	24 ft. 8 in.	33 ft. 10 in.
Sludge compartment:				
Depth below plane of slots	6 ft. 1 in.	8 ft. 9 in.	11 ft. 0 in.	22 ft. 6 in.
Depth below 18-in. neutral zone	4 ft. 7 in.	7 ft. 3 in.	9 ft. 6 in.	21 ft. 0 in.
Distance of lowest point of overflow below 18-in. neutral zone	2 ft. 6 in.	2 ft. 0 in.	2 ft. 0 in.	13 ft. 0 in.
Depth below overflow to adjacent compartment	2 ft. 1 in.	5 ft. 3 in.	7 ft. 6 in.	8 ft. 0 in.
Cubic feet per capita	1.40	1.49	1.88	2.40
Number of hoppers	8	5	3	3
Ease of intercommunication	Poor (2 ft. square opening)	Poor (opening 20 by 24 in.)	Good	Good
Scum compartment:				
Cubic feet per capita	0.76	0.72	1.59	0.55
Area, gas vents; percentage of tank area	14.8	14.3	15	26.8
Area, gas vents; square feet per cubic foot sludge capacity	0.034	0.023	0.031	0.0133
Loading deposited solids:				
Pounds per year per cubic foot sludge and scum space	14.2	10.4	13.1	9.2
Pounds per year per cubic foot sludge space	21.9	15.5	24.1	11.3
Pounds per year per cubic foot sludge space after deduction 18-in. neutral zone	30.0	18.9	30.9	12.3
Pounds per year per cubic foot scum space	40.4	32.1	28.5	49.7
Pounds per year per square foot gas-vent area	644	674	777	849

Digestion Chamber.—Obviously the digestion period at Plainfield is too short because the sludge is not completely digested. The tanks could not have been built deeper, as their bottom is in ground water present in unlimited quantities in coarse gravel strata. The cubic footage capacity beneath the slots was in line with available German experience when the designs were made, but the digestion period is less than half of that expected owing to a water content of about 94 per cent for the sludge in the digestion chamber as compared with the original assumption of 85 per cent. Shallow tanks have sometimes worked well and sometimes not. When digestion is proceeding badly, there is no doubt about the advantage of deeper tanks and the need of a greater size for the digestion chambers and a longer period of digestion than was expected from early data. Downes is proceeding with separate sludge digestion tanks which is the practical means of remedying the unfavorable conditions encountered. The supplementary tanks include arrangements for collecting gases, both to prevent their escape into the atmosphere and to make them available for heating the sludge during winter weather.

Separate Sewer Flow.—Plainfield sewage comes from a separate system of sewers and, according to the observations of the authors, such flows are much more likely to produce unfavorable conditions in two-story tanks than is the flow from combined sewers. The reason presumably is that street washings contain some mineral matter such as iron which may combine, in the process of the sludge decomposition, with sulphur compounds producing hydrogen sulphide and thus forming ferrous sulphide. This substance is gelatinous and a good coagulant. Thus, a double service may be rendered by keeping sulphur compounds in a condition where they will not escape into the atmosphere but will coagulate the sludge, and by making it more dense, thus guarding against the Plainfield predicament where the digestion period is too small on account of the high water content of the sludge. Downes states that the Plainfield conditions for sludge digestion are worse than is indicated by the relative water content of the sludge, in that there is a change in the structure and character of the sludge at lower water contents which seems to lessen the volume of the particles, as they become digested.

Sewage Composition.—In connection with acid foaming, the soap curd and fats at Plainfield no doubt are a factor in the

unfavorable digestion experiences in the two-story tanks there. Probably another factor is that there is no town garbage collection and private scavengers' efforts are directed more particularly to the sections of the city occupied by the well-to-do classes. Consequently kitchen wastes of a vegetable and fatty nature are no doubt discharged into the sewers and these add to the organic matters giving high CO_2 evolution and promoting acid fermentation. This can be corrected by liming, although a substantial period is required to overcome the effects of this type of biochemical decomposition after it has once become firmly established.

Adjustment of Reaction.—While the researches briefly outlined at the close of Chapter XXI show the great importance of this factor, when applied with systematic thoroughness, yet efforts to correct acidity in foaming tanks were made at Plainfield and elsewhere. Generally speaking, too much lime was added at a time to be effective. This mistake was not made, however, at the Pennypack Creek Imhoff tanks at Philadelphia or at some state institutional plants in Pennsylvania, where the sewage came from separate sewers. For the views of a decade ago of Imhoff, Stevenson and Fuller on liming and other items of Imhoff tanks see Engineering News, 1916, Vol. 75, pages 53, 430 and 572 and Engineering News-Record, 1918, Vol. 80, page 409.

Correction of acidity for sludge digestion seems to be far more necessary with the flow from separate than combined sewers. Perhaps this is to be explained by the silt and other detritus from street wash providing in the digestion chambers material to combine with the acid as it is formed by sludge digestion.

Stranded Solids.—The sewer system of Plainfield was built with extremely flat grades with a view to avoiding pumping. Brook water has at times been led into the main sewer and outfall sewer, but as a shortage of the public ground water supply precludes flushing with pressure water, this does not help at the upper ends of the sewer lines. Here sewage solids undoubtedly become stranded and biochemical activities are established which by chance or otherwise have been seriously disadvantageous to sludge digestion. This has been always true of the Plainfield sewage, going back to 1901, when single-story septic tanks were installed, and continued until 1916, when the two-story tanks and trickling filters were put in service.

Cross-walls in Digestion Chambers.—There is an unusual inequality in lengthwise distribution of sludge in the Plainfield digestion chambers, due to a number of cross-walls and the small openings therein. This condition was particularly intended by the designers, under the impression that sludge in different portions of the digestion chamber might be removed and mixed with well ripened sludge from other portions; or that, if necessary, partly digested sludge kept by itself might advantageously be removed and buried. This assumption is predicated upon the Madison-Chatham Imhoff tanks in which there are five compartments, three of which during a 2-year period of observation were always behaving well and one, and sometimes two, were not so behaving. The tanks which were behaving well were not always the same ones, thus leading to the view that biochemical decomposition has its caprices when treating the same sludge in different tanks of the same plant. Some of the tanks in this case were shallow and had a maximum depth of not more than 8 ½ feet beneath the trapped slot.

In concluding this recital of differences in viewpoints as to two-story tank design in 1913–14 and at present, and in conditions encountered at Plainfield as compared with those at many other plants, the most important feature to record is the improvement in basic design data made during that interval; and the fact that the supervising engineer, at Plainfield, is now able to correct the inadequate digestion period by the use of separate sludge digestion tanks and by collection of gas from the digestion chambers, both old and new. Thus Downes has assurance of satisfactory digestion at Plainfield such as has been obtained in so many plants elsewhere, without corrective arrangement.

CONFLICTING VIEWS ON DIGESTION IN IMHOFF AND SEPARATE SLUDGE DIGESTION TANKS

Some reference should be made here to debatable factors of sludge digestion which have come into discussion in recent years, in connection with the choice of two-story tanks as against separate sludge digestion. Suggestive data are presented here briefly without further comment. As time goes on and additional observations are made, the conflicting predictions and judgments will probably be more completely adjusted and explained.

Temperature.—The proponents of two-story digestion of sludge emphasize the fact that the sludge chambers of two-story tanks are kept warm by the sewage flowing through the upper story. Figure 27 (Imhoff, Fortschritte, p. 22) on p. 254 gives a clear picture of this situation at the clarification plant at Essen-Frohnhausen, where Imhoff tanks and separate secondary digestion tanks stand next to each other.

Similar observations are shown in Table 55 for Imhoff tank No. 17 at the Calumet Sewage Treatment Works of the Sanitary District of Chicago.

Temperature measurements in December at Hildesheim in the separate digestion chamber, on the other hand, showed 9 to 9.5° C. at a sewage temperature of 14 to 14.5° C. Kusch points out that this sludge temperature compares favorably with that of the sludge in the two-story tank at Frohnhausen.

Downes states that at Plainfield the temperature of the ground is the controlling factor and that temperature curves, for the winter months, are the same in the digestion compartment of the Imhoff tanks and in an isolated separate digestion tank, well protected by earth about the sides and protected by a wooden cover from the air.

The effects of temperature upon liquefaction and gasification of sludge are set forth in greater detail in Chapters XXI and XXV.

Seeding.—The advantages of continuous mixing of digesting sludge with fresh solids have been pointed out by Imhoff and confirmed by Rudolfs. Difficulties in bringing about seeding and mixing in the older Baltimore separate digestion tanks are real, but these have been considerably modified and reduced in the Kremer and other types where digestion is carried forward in series in two tanks, properly designed for mixing and inoculation.

Clarification.—In the complete separation of clarification and digestion chambers, advocates of separate sludge digestion see an advantage. Temperature variations of water and changes in atmospheric pressure may bring about exchange of materials, in two-story tanks, between upper and lower compartment. Avoidance of scour, with improved clarification in the two-story tanks, offers an opposite view. Probably each of the above views is partially correct, but all should be borne in mind in choice of method.

TABLE 55.—IMHOFF TANK TEMPERATURES, F°.
(Calumet Sewage Treatment Works, Sanitary District of Chicago)

Date	Air	Imhoff tank		Sewage temperatures plant	
		Top sedimentation chamber	Bottom sludge compartment	Influent	Effluent
1924					
January	27	Recording thermometer installed		43	42
February	37			42	41
March	40			43	41
April	54			47	46
May	54	51	49	51	52
June	66	56	53	57	58
July	71	61	58	62	64
August	70	65	61	65	66
September	59	63	60	63	64
October	56	61	57	61	62
November	44	54	52	55	55
December	44	44	47	46	45
1925					
January	25	41	43	42	41
February	31	43	46	41	43
March	38	43	47	41	42
April	52	49	49	46	48
May	57	51	52	52	53
June	72	60	58	60	61
July	75	66	63	65	67
August	76	70	67	68	69
September	73	70	67	69	70
October	47	59	62	60	60
November	38	52	58	50	52
December	25	45	46	46	47

CHAPTER XXIV

SEPARATE SLUDGE DIGESTION

SYNOPSIS

1. Description.—As its name implies this process deals wholly with the digestion of sewage solids in separate tanks. It has no relation directly to the sedimentation basins, although in some recent designs the sludge digestion tanks are placed between the settling tanks at about the same level. Most digestion tanks are entirely separate.

2. History.—Technically this method had its origin at Lawrence about 1899, although some precedent was provided by the sludge lagoons of Essen and elsewhere. It was first recommended by Hazen in 1906 for adoption by the City of Paterson, N. J. It was actually adopted by Birmingham, England, in 1912 and recently it has been installed at several places in Germany and the United States, in connection with various types of plain sedimentation tanks as outlined in Chapters XVIII and XIX.

3. Extent of Use.—This method serves over 1,000,000 people at Birmingham, the largest inland city of England. It was also adopted at Bath, England, in 1922. There are 14 plants of this type in Germany in connection with Kremer tanks. It is included in the new projects in Stuttgart, Munich and Zurich. In the United States the principal installation is at Baltimore where it has been gradually developed since 1912. Alvord has used it at the Great Lakes Naval Training Station, Madison Wis., Lincoln, Nebr., and other places. There are 14 such plants in the United States in connection with Dorr clarifiers. Different arrangements are in use at Merchantville and Palmyra, N. J., and Larchmont, N. Y.

4. Capacity of Tanks.—This depends on temperature, quality of sewage, water content of entering sludge and other factors. Birmingham and Baltimore experiences show that caution is necessary in considering short time experiences with tanks of relatively smaller size. The cubic feet of capacity allotted per

capita connected with the sewers range for different plants as follows:

Birmingham, 9.2; Kremer tanks, 1.2; Dorr plants, 1 to 3.3; Bath, 3.1; Munich, 1.7; Zurich, 3.8; Baltimore (1913), 3.95, (1920), 1.60, and (1925), 3.57; Lincoln, 1.25.

5. Improvements in Process.—Experiences on a small scale at Chicago and Philadelphia about 1911 were not satisfactory. Solids were lifted above the flow line where they were not completely digested and where they gave some trouble from odor. These difficulties were corrected partly by more efficient mixing methods and particularly by the later practice of carrying out the process with open tanks in two stages, whereby partially digested sludge from a primary tank was always delivered into a secondary tank for complete digestion, or in covered tanks where provision for submergence and digestion of scum was made. Since it takes several months ordinarily to get the contents of a digestion tank well ripened, modern practice has made it essential to mix incompletely digested sludge with seeded sludge. The aggregate effect of these successive steps in the development of the process in respect to thorough mixing, seeding with ripened sludge, adjustment of reaction, and provisions for sufficient tank capacity for complete digestion, have transformed this process from a debatable status to assured success.

6. Efficiency.—Notwithstanding the difficulties earlier met at Baltimore and elsewhere from the use of tanks of inadequate size and with inadequate mixing and seeding, the experiences at Birmingham, England, and elsewhere show that this process can be made efficient in conversion of sewage solids to an inodorous condition. This experience and the collection of gas and submergence of scum make this process thoroughly efficient for digesting sludge without odors.

7. Advantages.—An advantage of this process is that it can be readily adapted to correct deficiencies in capacity of two-story tanks or of other methods for the disposal of undigested sludge. (See Plainfield, N. J., experience at end of this chapter.) In particular it is advantageous in that it permits the sludge obtained from sedimentation tanks in built-up areas of the city to be digested and disposed of in isolated areas to which the sludge may be pumped at relatively small expense.

8. Present Status.—English and German experiences show that this method is practicable and efficient and that its adoption

is rapidly increasing, particularly in connection with arrangements for the collection and utilization of gas. In America its status is less well established largely because of unsatisfactory results at the Chicago and Philadelphia testing stations and the experiences at Baltimore with digestion tanks built from time to time during the past 14 years, frequently too small in size and not operated in much of its history in accordance with the best 1926 practice. There is nothing in any of the American experiences to cause hesitancy in adopting this method in conformity with successful practice in Europe. There is little to be said in comparing the process with two-story septic tanks without dealing with cost data which are not now available on a comparable basis. In fact, it is not yet definitely known what storage capacity it is prudent to provide under different local conditions.

CHARACTERISTICS OF METHOD

Effect of Temperature.—There has been considerable discussion of the relative merits of separate digestion and two-story tanks as regards the temperature prevailing in the digesting sludge, since the activity of digestion is materially increased by a few degrees difference in temperature. This fact is particularly important during the winter months in cities having the climate of the northern portion of the United States. In the case of separate sludge tanks, built above ground and uncovered, there may be a reduction in the rate of digestion during winter months, which means that substantially greater volume of digesting space should be provided. With plants located in semi-tropical locations such as Florida, there is little advantage in having the sludge digestion chambers deep in the ground and surrounded with ground water, as compared with tanks exposed to the hot sun. Furthermore, the digestion tanks may be built between the settling tanks at about the same level.

A series of temperature measurements of the sludge in one of the digesting tanks at Baltimore was obtained during the winter of 1922–23. The temperatures were obtained in a tank 24½ feet deep at the center by means of a recording thermometer at distances of 2, 11 and 20 feet from the top of the sludge. At the 2-foot depth the temperature ranged between 36 and 44° F.; at the 11-foot depth, between 42 and 47°, and at the 20-foot depth, between 42 and 48°. The minimum temperature of the

air at any one time was 7° and the maximum 63°. The lowest average daily temperature of the air was 20°.

Seeding and Mixing.—At times it may be found that the digestion process does not proceed satisfactorily and that the type of fermentation is such that a nuisance from odor is created. In such cases, it may prove necessary to transfer the sludge to another tank, at the same time mixing it and seeding it with material which is digesting in a satisfactory way.

There is undoubtedly considerable advantage at times in being able to stir sludge in the process of digestion and, in the case of relatively small plants, it is likely that mechanical arrangements such as paddles may prove advantageous. In most cases, however, it is doubtful if such arrangements are practical. It is more probable that suitable pumps with adequate piping connections, which will permit a convenient and economical transfer of sludge from one tank to another, and the mixing together of sludge from two or more tanks, will be most practical in securing the best results.

From Schaetzle's experiments at the Baltimore plant, his general conclusions are that digestion takes place most rapidly in the first few weeks, after which it slows down until reaching a point of apparent equilibrium, when it continues very slowly, if at all. If raw sludge is seeded, the time required to obtain a sludge containing 53 per cent or less of volatile matter is dependent upon the organic content of the initial mixture of raw and digested material. Under similar conditions, digestion is more rapid if a tank is seeded. During the warm seasons at least 1 month should be allowed for the digestion of seeded sludge, if the entire two-thirds volume is to be replaced by raw sludge at every filling. Raw sludge left to itself requires at least 14 months for complete digestion.

He also indicates the advantage of agitation to provide for adequate mixing of raw and digesting material.

Some work has been done at the Baltimore plant in an attempt to discover the bacterial forms which aid digestion. Tentatively it is found that the bacteria which cause gassing and liquefaction of sludge are of two distinct types and the best liquefiers are not gas formers.

Reaction.—Rudolfs' work in New Jersey and that of Baity at Harvard demonstrate, at least on a laboratory scale, that digestion can be relatively closely controlled by regulating the

hydrogen-ion concentration of the sludge. In other words, they demonstrate that the nature, the rate and the amount of digestion are sensitive to modifications in sludge reaction. Their findings are elaborated in Chapter XXI.

Odor Production.—With open tanks, particularly large ones, and with certain sewages, the digesting sludge may produce foul odors. Birmingham and many other experiences, however, indicate that there is no great danger from nuisance if the tanks are intelligently and carefully manipulated under the direction of a skilful manager.

It is evidently perfectly feasible to cover sludge digestion tanks and collect the evolved gases and thus completely eliminate the possibility of odors. That this procedure has proved practicable is indicated in the observations set forth in Chapters XXI and XXV.

Separate Sludge Digestion for Activated Sludge.—At Indianapolis, the sludge from the fine screen concentrate is being mixed with the excess activated sludge and run into separate sludge digestion tanks which are simply deep lagoons with earth embankments without any lining. The additional capacities necessary for disposing of excess activated sludge are discussed at greater length in Chapter XXXIX.

Scum Formation.—A striking characteristic of most separate sludge digestion tanks is the tendency to form a heavy scum, which in many cases becomes 2 or 3 feet thick. While this is looked upon as advantageous at Birmingham and Baltimore in conserving the heat of the digesting sludge and minimizing the dispersing of odors, it is probably true that the digestion of the solids in the scum does not proceed as satisfactorily as could be desired.

The formation of a heavy scum may complicate the drawing off of the supernatant liquor when it is desired to add fresh sludge, and generally it will be helpful to provide a series of draw-off pipes at different levels or a movable draw-off pipe which can be used for this purpose.

Sludge Removal.—The removal of digested sludge presents some difficulties, and this is particularly so with relatively large, flat-bottomed tanks. With the large rectangular digestion tanks at Baltimore it has been found, at times, that fresh undigested sludge from the inlet end of the tank would travel across the tank and pass out when an attempt was made to draw fully

digested sludge. At other times, there has been a tendency for dead areas of digested sludge to form which would not flow to the outlet pipe. Relatively deep tanks with hopper bottoms will undoubtedly assist materially in securing only fully digested material, when sludge is drawn. Suitable mechanical cleaning arrangements will also prove helpful in this regard. Such tanks, however, are obviously somewhat more expensive to construct, particularly in the case of large plants.

Two Sets of Tanks.—It is desirable to digest the sludge successively in two or more separate tanks, as this facilitates mixing the fresh or partly digested sludge with ripe sludge. After drawing sludge there is always allowed to remain a volume of ripe sludge equal to about 30 per cent of the tank capacity. Rapid and effective digestion is aided by the mixing which the sludge receives in being pumped from one tank to another. This procedure is practiced at Birmingham, where preliminary digestion takes place in a tank of 3 months' holding capacity and then the sludge is pumped into a secondary digestion tank, where it is held for another 3 months. The practice is similar at Bath, England, but the period of digestion is only 6 weeks, probably due to the unusually high temperature of the sewage. Sissons, City Engineer of Bath, considers 6 weeks ample in summer, but too short in winter.

Period of Digestion.—It has been currently assumed that solids will be thoroughly digested in anywhere from 6 weeks to 6 months, depending upon character of organic material, temperature, seeding, etc. This fact also serves to emphasize the necessity of providing sufficient space and of starting new digestion of sludge in warm weather. Even under the most favorable conditions, at initial starting of a plant the period for digestion of the first sludge may indicate an apparent period for digestion of greater length than will subsequently be found necessary with properly seeded and mixed sludges. In view of present-day preliminary observations on the effect of reaction upon rate of digestion, however, shorter periods may prove adequate in the future, particularly if the temperature be kept near the optimum.

Water Content.—There is some danger in arbitrary comparisons of successful performance at different plants with different sludge storage capacities per capita, due to the fact that different sludges have entirely different water retention possi-

bilities. The result of such variations in water contents of sludges, due perhaps to their physical and chemical structure, is that a given storage capacity for a sludge containing 94 per cent of water cannot be adapted to the requirements of another tank with a sludge capable of consolidating to an average of about 85 per cent moisture. What elements in the process of hydrolysis regulate such varying contents is not now fully understood. Downes, however, points out that the variations in sludge bulk may be considerably greater than would be accounted for by the mere ratios of 6 to 15 per cent of dry solids in the sludge.[1]

Preliminary Decantation.—The moisture content and the consequent volume of sludge can be advantageously reduced by preliminary settling and decantation of supernatant liquor. This is accomplished, for example, by the preliminary decantation tanks at Zurich and by the sludge cylinder arrangement at the bottom of the Kremer type of tanks.

ENGLISH SUCCESSES

Birmingham, England.—At Birmingham, the deposited sludge is removed every week from the sedimentation basins by decanting the liquid and pumping the solids to the digestion tanks by means of steam-driven, direct-acting sludge pumps.

To secure rapid and effective digestion, it is highly important that the raw sludge should be thoroughly mixed with a proportion of sludge which is in a state of active fermentation. At Birmingham this is done by drawing ripe sludge from a digestion tank simultaneously with fresh sludge from a sedimentation tank and pumping the mixture into a digestion tank which, after sludge withdrawal, invariably contains some 30 per cent of its capacity of sludge in a state of complete digestion. The sludge is always pumped into and drawn out of the bottom of the digestion tanks, in order to provide for adequate mixing and avoidance of odors.

The early tanks at Birmingham were rectangular in shape, 12 to 15 feet in depth with vertical masonry side walls and relatively flat bottoms. The later tanks were 20 feet deep, and Whitehead indicates that new tanks would approach 25 feet in depth.

The more recent tanks at Birmingham have earthen embankments, the bottoms and sides being lined with a comparatively thin concrete paving, making a cheap type of construction.

[1] Downes, Discussion on Eddy, "Imhoff Tanks—Reasons for Differences in Behavior." Trans. A. S. C. E., Vol. 88, 1925, p. 516.

At the Birmingham works in 1923, sludge digestion capacity was available to the extent of about 9.2 cubic feet per capita. With a new design it is said that 6.0 cubic feet might suffice. The volume of the sludge from the Birmingham combined sewerage system has been stated to be fully six times as much per capita as that from the Baltimore system, due largely to differences in water content, street wash and industrial wastes.

Bath, England.—This sewage is from a population varying from 77,000 to 110,000, according to holiday seasons at this popular resort. It is entirely domestic in character, with no trade wastes, and is from a combined sewerage system. Separate sludge digestion tanks were constructed about 1923, upon the recommendation of O'Shaugnessy. Digestion is carried out in two stages. The primary digestion tanks are old storm water tanks, 51 by 62 feet in plan and 18 feet deep. These receive sludge every day from Dortmund settling tanks. One foot of ripe sludge is always left in the bottom of the primary digestion tanks. The fresh sludge is pumped in at the bottom and the tanks are filled in rotation.

The nine secondary sludge digestion tanks built in 1923 are 20 by 40 feet in plan and 20 feet deep. Additional secondary sludge digestion tanks are necessary for winter digestion. Since the sewage has an unusually high temperature, about 6 weeks appear to suffice for complete digestion in summer, the process being somewhat slower in winter.

We found the sludge digestion tanks to be operating well, with no odor production and with a suitable character of sludge drawn onto the beds.

EXPERIENCES AT BALTIMORE, MD.

Early History.—Separate sludge digestion was started at Baltimore in 1912. Later difficulties experienced in adequate digestion of the suspended materials in the existing Imhoff tanks led to expansion. The sludge tanks vary in size from 20,600 to 204,200 cubic feet. So far as available evidence indicates, as good results are obtained with one size of unit as with another. The operators of the works feel that for a large plant it is more logical to build large units inasmuch as they cost less. Their experience, likewise, indicates that the construction of several sludge inlets and outlets at different elevations in each sludge tankh as been a wise policy, as digested sludge is frequently

found at various elevations in the sludge tanks and provisions are thus made to remove it.

Inadequacies in Sludge Capacity.—The amount of sludge storage space provided per capita at Baltimore has been regulated more by budget deficiencies than by actual plant requirements. Likewise the design of sludge tanks has gone through considerable change since 1912. The capacity of separate sludge digestion tanks at various intervals during the period from 1912 to 1925, inclusive, is shown in Table 56.

TABLE 56.—CAPACITY OF SEPARATE SLUDGE DIGESTION TANKS AT BALTIMORE, MD.

Year	Tributary population	Tank capacity, cubic feet		Capacity per capita, cubic feet	
		Total	Available allowing 2 feet free-board	Total	Available allowing 2 feet free-board
1912	50,195	609,000	525,000	12.13	10.46
1913	132,875	609,000	525,000	4.58	3.95
1914	220,990	609,000	525,000	2.76	2.38
1915	337,555	938,600	817,800	2.78	2.42
1916	415,215	938,600	817,800	2.26	1.97
1917	460,785	938,600	817,800	2.04	1.77
1918	497,805	938,600	817,800	1.89	1.64
1919	505,270	938,600	817,800	1.86	1.62
1920	517,225	938,600	817,800	1.81	1.58
1921	532,840	938,600	817,800	1.76	1.53
1922	560,815	1,568,700	1,367,300	2.80	2.44
1923	586,820	1,568,700	1,367,300	2.67	2.33
1924	645,225	2,728,300	2,406,700	4.23	3.73
1925	673,240	2,728,300	2,406,700	4.05	3.57

In 1920, notwithstanding a material increase in sludge digestion capacity, the population had grown so rapidly that there were only about 1.60 cubic feet per capita of sludge space. Under these conditions, it was hardly possible to secure a thoroughly digested and satisfactory sludge, and material increases in the sludge digestion capacity were needed.

On January 1, 1925, Keefer estimated that 3.73 cubic feet per capita were available at the works. The average quantity of undigested sludge from 1915 to 1924 inclusive was 0.25 cubic yard per year per capita, and 7.17 cubic yards per year per million gallons of sewage. From subsequent observations he further states that the above-mentioned volume per capita is none too great, and that probably it will have to be increased to 4.0 or 5.0 cubic feet per capita, before fully satisfactory results will be obtained.

Experience at Baltimore would indicate that more digestion space is needed than in Imhoff tanks. The chief reason for this is that the water content of the sludge is higher, being a little above 93 per cent when it enters the tanks. The average water content of the digested sludge put on the drying beds from 1920 to 1924 was 91.8 per cent. With such a sludge, more drying bed area is needed than if Imhoff tanks were used.

Method of Operation.—At Baltimore, the hydrolytic or sedimentation tanks are kept in operation until they show signs of undesirable septic action or until the laboratory analyses show the settling efficiency to be below normal. The supernatant liquid is then delivered to one of the other hydrolytic tanks and the residual sludge is pumped into one of the separate sludge digestion tanks.

The sludge removed from the sedimentation tanks to the sludge tanks is usually in an undigested state, containing when dry in the neighborhood of 65 to 70 per cent volatile matter. The amount of time required to digest the sludge fully has ranged from 3 to 6 months. The digested sludge is very similar to Imhoff sludge. It has the same general characteristics and dries as well.

Within the last 4 years, when additional sludge capacity beyond the available sludge digestion tanks was desirable, the existing Imhoff tanks were used for that purpose. They produced a well digested sludge which was free from objectionable odors and which dried well on sand beds. The efficiency with which they produced these results was dependent upon the fashion in which they were seeded and the point of the tank from which digested material was removed.

Form of Tanks.—The first three separate sludge digestion tanks built at Baltimore were rectangular in shape, 140 feet long, 103 feet wide and from 13½ to 15½ feet in depth. Sludge was fed into these tanks through a cast-iron pipe line which was attached along the top of the walls opposite the outlet of the tanks. In order to prevent odors from escaping when raw sludge was fed into the tanks, the pipe extended below the surface of the sludge. The capacity of these tanks amounted to 608,700 cubic feet. Thick scum formation was characteristic, and in order to pump the sludge to the points of disposal, it was frequently necessary to break up the contents of the tank with a stream of water. Undigested sludge also flowed directly underneath the scum to

the outlets, with the result that in 1921 additional outlets were built at higher elevations to give greater freedom or variety in withdrawal of sludge. In 1915, sixteen additional tanks of an entirely different design were built. They are all the same size and type. They are circular, 38 feet in diameter, 24½ feet deep, with the bottoms hopper-shaped and with a depth of hopper of 9½ feet. One outlet and one inlet pipe were provided for each tank on the assumption that the digested sludge would form at the bottom while the undigested material would remain at the top. Unfortunately, the reverse took place and considerable difficulty with operation therefore occurred.

An additional sludge tank was built in September, 1921, 150 feet long, 86 feet wide, with a depth varying from 16 feet 3 inches to 21 feet 3 inches. Sludge may be let into the tank at opposite ends through a pipe inlet at the bottom of the tank and sludge may be withdrawn from opposite sides of the tank and at different elevations. The capacity of this tank was 233,000 cubic feet. It is built entirely of reinforced concrete. The recent tanks have likewise been rectangular in form and have also been built entirely of reinforced concrete.

Odors.—The experiences at the Baltimore works are especially pertinent in matters of odor production. It has been frequently stated that the operation of the separate sludge digestion tanks at Baltimore was attended by objectionable odors. The actual condition of affairs, however, is not so simply stated. In the first place, the production of odors at one period of operation of these tanks was primarily due to insufficient sludge digestion capacity, as a result of inadequate funds for increasing digestion space. This situation is well illustrated in Table 56 where it may be noted, for the period 1917–21 inclusive, that sludge capacity was inadequate.

Consequent upon these inadequacies, filling and drawing of sludge from the digestion tanks were necessitated regardless of the time the sludge had remained in the respective units. This procedure resulted naturally in the removal and disposal of partially digested material with objectionable odor. Coupled with these facts of partial digestion was the inadequacy of sludge drying bed area during the same period noted above. This lack of capacity likewise caused difficulties which led to some odors.

In other words, when odors did occur in connection with the separate sludge digestion, their cause was not a deficiency in

process, but an inadequacy in operating personnel and plant capacity.

At Baltimore since 1921, little, if any, of the odors at the works are properly chargeable against separate sludge digestion. By far the greatest offenders are the plain settling tanks, discussed in Chapter XIX and, in a less degree, the trickling filters.

OTHER AMERICAN EXPERIENCES

Lincoln, Nebr.—Separate sludge digestion tanks were completed for Lincoln, Nebr. in October, 1923. The tanks are 27 by 27 feet in plan, with vertical walls 14 feet deep and hopper bottoms of 45 degree slope. With a population in 1922 of 50,000 the sludge digestion storage was equivalent to 1.25 cubic feet per capita.

Larchmont, N. Y.—At Larchmont, four similar sludge digestion units have been in operation since the early part of 1926. They are 16 by 16 feet in plan, with hopper bottoms. The maximum depth of each is 14.8 feet, with a depth above the hoppers of 6 feet. Their approximate capacity is 1.66 cubic feet per capita. The collection of gas from these tanks is described in Chapter XXV.

Merchantville, N. J.—The old Merchantville plant consisted of a septic tank and sand filters. In later years an additional sewerage system and disposal plant were built for Merchantville and Pensauken. New settling tanks with Link Belt sludge collectors were built and the old septic tank was used for the digestion of sludge. The tank was reconstructed and is 45 feet wide by 55 feet long, with a total depth of tank of 11 feet and of sludge of 10 feet. The capacity is about 20,000 cubic feet for a population in 1925 of 9000. The contributing population in May, 1926, was estimated by Blew and Tark as 10,000 so that approximately 2 cubic feet per capita are provided for digestion.

The sludge travels a distance of 240 feet in the process of digestion so that the opportunity for careful checking of the results at various points in its transit is available. The pH value of the raw sludge is 6 and drops to 5.8 further on in the tank. Blew and Tark indicate that the increase in acid is probably due to the decomposition of soluble carbohydrates, the later formation of ammonia causing an increase of pH value with increase in production of gas. The dried sludge from the Merchantville

beds showed in 1926 an ash content of 59.8, volatile matter, 40.2, nitrogen, 2.7 and phosphoric acid, 1.2 per cent.

Palmyra, N. J.—An interesting installation of the Kremer-Kusch type of separate sludge digestion tank, described later herein, was completed in August, 1922, at Palmyra, N. J., serving a present population of about 3500. Primary and secondary digestion chambers are in use. The first compartment is from 8 to 14 feet deep, while the second is from 14 feet 8 inches to 17 feet 4 inches deep, both sloping down with the flow. The total capacity of the tank is 6000 cubic feet.

The Department of Health of New Jersey reported in 1924 that the chemical analysis of the sludge discharged to the sludge drying bed showed approximately the same results as the average Imhoff tank sludge. Slightly more complete digestion was indicated than with Imhoff tank sludge. Blew and Tark, in 1926, reported that the dried sludge from the beds showed 37.2 per cent ash, 62.8 per cent volatile matter, 3.5 per cent nitrogen and 1.0 per cent phosphoric acid.

The results of operation have been excellent.

DORR DIGESTION TANKS

At a number of relatively small plants recently constructed, separate sludge digestion tanks have been installed to handle the sludge coming from settling tanks equipped with Dorr Thickeners. A number of these are equipped with revolving mechanical devices of the Dorr Company for spreading the fresh, incoming sludge over the surface of the digesting sludge and also for breaking up such scum as may rise to the surface. Additional equipment is provided for moving the old sludge at the bottom of the tank towards the sludge outlet.

Hartford, Wis.—This plant consists of a Dorr clarifier, a sludge digestion tank and a sludge bed. The digester is 38 feet in diameter with an effective water depth of 15 feet. It is equipped with a mechanical agitator of the Dorr type, consisting of 2 sets of arms, one operating at the bottom and one 2 inches above the surface of the sludge. The arms revolve once in 16 minutes.

The plant was started in August, 1924, two wagon loads of horse manure being used to seed the digestion tank. Bacterial action started in a few days, as evidenced by gas bubbles, and

proceeded throughout the winter. The digester has a wooden cover, supplemented during the winter with marsh hay. In the following April sludge drawn from the tank had a slight tarry odor, was full of gas, black in color and fully equal to good two-story tank sludge. The sludge dried readily in 10 days, notwithstanding that it rained twice.

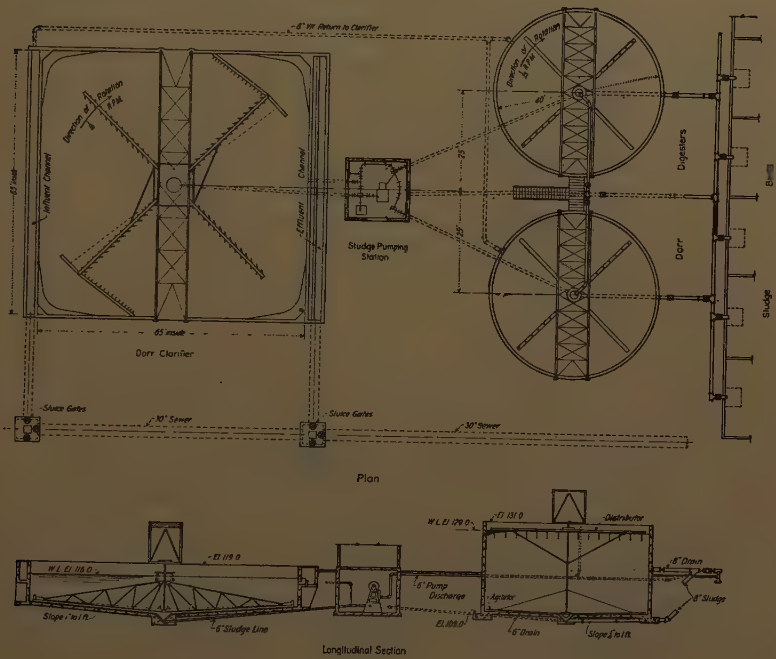


FIG. 36.—Door clarifier and digestion unit.

In Table 57 data are given with reference to the several plants installed by the Dorr Company.

Figure 36 shows a section of a typical plant comprising a Dorr clarifier and Dorr digestion unit.

TABLE 57.—DORR CLARIFIERS WITH SEPARATE DIGESTION OF SLUDGE

	Population served	Size of clarifier, feet	Size of digester, feet	Volume treated, m.g.d.	Detention clarifier, hours	Digester cubic feet per capita
Brownsville, Tex.	15,000	45 diam.	35 diam. by 16 deep	1.0	2	1.0
Charlotte, N. C.	50,000	100 sq.	37 sq. by 16 deep (4)	2.6	4.8	1.15
Bartow, Fla.	4,000	30 sq.	26 diam. by 15 deep	0.4	2	2.0
Hartford, Wis.	5,500	30 sq.	38.5 diam. by 16 deep	0.4	2	3.4
Sheboygan, Wis.	5,000	30 sq.	36 diam. by 16.8 deep	0.5	2	3.0
Kiel, Wis.	2,000	20 sq.	25 diam. by 15 deep	0.16	2	3.7
Wheaton, Ill.	7,500	30 sq. (2)	30 sq. by 24 deep (2)	0.75	4	2.5
Leetonia, Ohio	2,688	25 sq.	12.5×26 rect. by 16 deep (2)	0.3	3	2.8
Ridgewood, N. J.	20,000	46 sq.	30 sq. by 15 deep	1.5	2	2.0
Vero, Fla.	4,000	30 sq.	30 diam. by 17 deep	1.2	2	3.0
Lakeland, Fla.	25,000	65 sq.	40 diam. by 20 deep (2)	2.5	2	2.0
Sioux Falls, S. D.	50,000	70 sq. (2)	85 diam. by 25 deep (3)	8.0	2.5	8.2(a)
Antigo, Wis.	11,180	35 sq.	50 diam. by 17 deep	0.9	2	3.0
Butler, Pa.	26,000	50 sq. (2)	16 sq. (8)	2.6	2	1.5

(a) Large capacity due to large volume trade waste making bulky sludge. Depths of digester tanks are from floor line to top of sloping bottom.

It is understood that the capacity given for digesters is for ultimate population to be connected, not the present. Seibert gives capacity in cubic feet for present as 5.3 for Hartford; 13.57, Sheboygan; 7.35, Kiel; and 8.4 for Leetonia.

GERMAN EXPERIENCES

Kremer-Kusch Tanks.—An interesting type of separate sludge digestion tank has been developed in Germany and installed in a number of towns. It is known as the Kremer-Kusch system. These plants have a so-called Kremer cell, which is a clarification tank with a steep hopper bottom, the apex of each hopper being equipped with a sludge cylinder for securing greater concentration of the sludge, as shown more clearly in Fig. 37.

The essential feature of the process, however, is the provision of two chambers for sludge digestion. In the first chamber rapid digestion of the mixed sludge and sewage drawn from the clarifying cell takes place and, after a certain period, the partially

digested sludge is removed to the final digestion chamber where it remains under a layer of sewage until fully digested. The predigestion chamber possesses a relatively large bottom surface and small depth, whereas, in the final chamber, conditions are reversed. It is stated that this arrangement is favorable to the process of sludge digestion. The results at a number of plants of this type have been highly satisfactory.

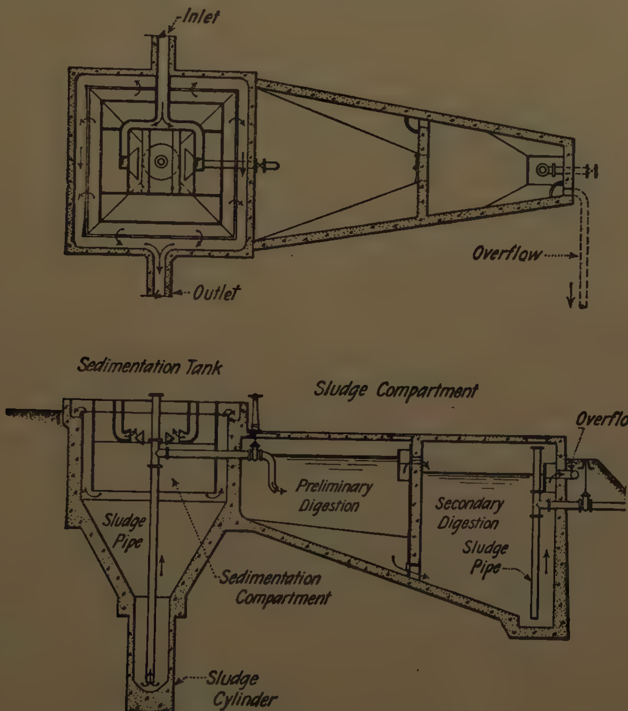


FIG. 37.—Kremer sedimentation tank with sludge compartment (separate sludge digestion).

The sludge compartments are arranged in some cases so that the flow from one to another is by gravity. In other places, on account of ground conditions, they may be set at higher levels than the clarifying tanks and the sludge pumped to them. It is customary to sink them in the ground and to bank earth over and around them so that the temperature of the digesting sludge is kept as high as possible. Where the digestion units are covered, there is no trouble from odors. A good account of the Kremer tank is given in an article by Kusch in the Technisches Gemeindeblatt, Feb. 5, 1925, No. 21, pp. 261–267.

Kusch suggests Kremer separate sludge digestion arrangements for (*a*) sewage with high organic content and (*b*) sewage from separate systems, because in each case there is a large proportion of organic material per unit of water. It is his contention that, in two-story tanks, such high organic content in the sludge compartment causes bad clarification due to possibility of mixing clarified water with sludge materials.

For separate sludge digestion plants of the Kremer type in Germany, it has been stated that a sludge capacity of about 33 liters (1.2 cubic feet) per capita is sufficient as compared with 20 to 50 liters (0.7 to 1.7 cubic feet) per capita provided in the digestion compartments of Imhoff tanks.

The following tabulation lists the capacities of typical Kremer-Kusch separate sludge digestion tanks at various towns in Germany.

	Plant installed	Population	Sludge capacity, cubic feet per capita
Hildesheim	1916	55,000	1.9
Amberg	1917	30,000	1.2
Gerdauen	1919	5,000	1.2
Ohrdruf	1915	36,000	0.9
Prussian Holland	1919	6,000	0.9
Prenzlau	1916	27,000	0.9

This type of plant is in use at some fourteen places in Germany, the more important of which are those noted above.

Höchst a. Main.—Only 4 weeks are allowed here for digestion, with an apparent capacity or sludge volume of only 0.8 cubic foot per capita. Sludge is withdrawn from the settling tanks every 1 to 3 days and transferred to eight sludge tanks. On our inspection of the plant in January, 1926, the sludge as withdrawn from the settling tank was black, partially digested and showed some odor. The sludge tanks are 100 by 13 feet in plan and 7½ to 10 feet deep. Little difficulty with odors has been experienced at the plant.

The sewage of Höchst a. Main is from a combined system, with no intervening cesspools on the house sewers. The population connected is 35,000.

Stuttgart.—Part of the sludge is digested in separate tanks adjacent to the "Neustadt" settling tanks, with a sludge capacity of about 2.3 cubic feet per capita. Sludge is removed hydraulically every day from the clarification units. The sludge tanks are about 85 by 65 feet in plan and from 16 to 24 feet deep. The sewage is largely from a combined system serving a population of approximately 223,000 in 1925. The arrangement of the plant is shown in Fig. 38.

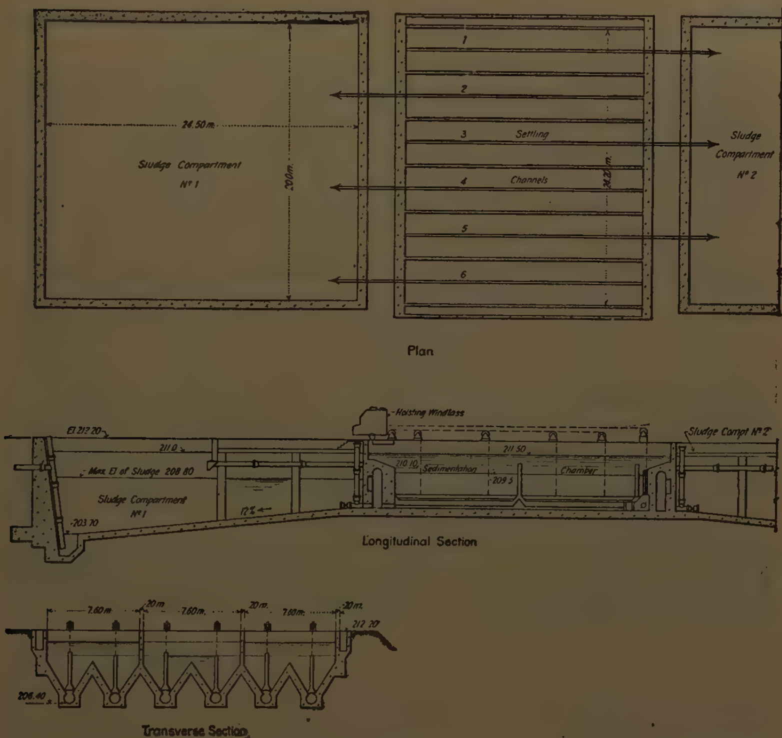


FIG. 38.—Neustadt tank, with separate sludge digestion.

Munich.—The available volume of separate sludge digestion tanks at Munich is about 1.7 cubic feet per capita. Sixteen settling tanks of Travis type, equipped with colloiders, are in use. Each clarification tank has two settling compartments and a single sludge compartment at practically the same elevation. Each sludge compartment has a capacity of approximately

52,000 cubic feet. The sewage is derived from a combined system. The population approaches 500,000.

The settling compartments are separated by dividing walls from the sludge compartments. A continuous flow of fresh sewage passes through the sludge compartment, which is in turn clarified again before going into the effluent. The purpose of this small minor flow is to remove decomposition products in the sludge compartment.

Zurich, Switzerland.—The difficulty of excessive moisture in the sludge placed in separate digestion tanks is to be met at

FIG. 39.—Sludge beginning to gasify, Baltimore sewage works.

Zurich by holding the sludge from the Travis settling tanks in a small 1-day preliminary sludge tank, of about 1800 cubic feet capacity, for removal of water before it is put into the sludge digestion chambers proper. Each of the sludge tanks has one of these decantation basins attached to it, as shown in Fig. 40. The present sludge tank capacity, allowing 6 months for digestion of solids, is about 3.8 cubic feet per capita. The same purpose is sought in the construction and use of the deep sludge cylinder below the settling tanks in the Kremer installations described on pages 308 and 309.

CAUTION NECESSARY

Long-term operating experience with the relatively low sludge capacities noted above should be available, in the light of Birmingham and Baltimore experiences, before too much emphasis should be placed upon them, and especially in view of the fact that at some plants in Germany other facilities for receiving sludge, such as drying beds and farm land, have been available. This caution is given further basis by Sissons' observation at Bath, England, to the effect that their available sludge capacity,

Fig. 40.—Preliminary sludge decantation tank, Zurich, Switzerland.

3.1 cubic feet per capita, is too little during the winter. This is particularly important, since at Bath temperatures of sewage favorable for digestion are practically always available.

SEPARATE SLUDGE DIGESTION AT PLAINFIELD, N. J.

Supplementary Digestion.—At the Plainfield plant an attempt has been made by Downes to overcome the shortage of sludge digestion space in the Imhoff tanks by the use of separate sludge digestion tanks. For this purpose three tanks have been constructed of earth embankment, and the fresh solids have been pumped, by means of diaphram sludge pumps, from the bottom of the Imhoff tanks to these earthen digestion tanks. Digestion has been excellent and, probably due to the longer time available

for digestion, he has been able consistently to secure sludge of 9 per cent solids as compared with 6 per cent in the Imhoff tanks.

Avoidance of Odors.—In an attempt to minimize odors about the plant, a floating cover, invented by the superintendent, has been floated on the surface of the sludge in one of these tanks. The original purpose of this cover was to collect the gases in order to dispose of them without nuisance by burning. It developed, however, that the depression of the floating solids into the liquid and the complete exclusion of air are said to have inhibited the production of certain odorous compounds otherwise formed.

Heating of Sludge.—The gas has been burned in an ordinary Ruud water heater which is attached in parallel with a coal-burning water heater used to heat the sludge in the digestion tank. The heating of the 25,000 cubic feet of sludge in this tank, at a rate which would maintain the summer temperature throughout the winter, required only 150 pounds of coal per day, when no gas was used. The production of gas at 68 to 70° F. varied from 500 to 4000 cubic feet per day. The gas was approximately 75 per cent methane. The variation in quantity of gas produced was dependent upon variations in the addition of fresh solids and could be maintained, no doubt, at the higher figure by preserving the proper biological balance, by proportioning fresh solids to old ripe sludge. Comparison of the heat value in the coal used and in the gas produced indicates that the gas is more than sufficient to maintain optimum temperature for digestion.

Operating Data.—In a personal communication to the authors Rudolfs has furnished operating experiences for 6 months as follows: The tank digested, during the period of October 14, 1925, to April 14, 1926, fully as much fresh solids as the Plainfield Imhoff tanks do during the summer (results compared with the results obtained over several years on Imhoff tanks). The average temperature in the sludge digestion chamber in the Imhoff tanks at Plainfield during the summer months is 65° F. The average temperature in the separate sludge digestion tank was 56°. The highest being 68° and the lowest being 48° F. At that temperature one would expect that digestion in the separate sludge digestion tank should have gone on at a slower rate. However, all the material entering the separate sludge digestion tank during this period was adjusted to pH 7.3. The sludge produced from the separate

sludge digestion tank was as good as the best Imhoff tank sludge obtained. The sludge present in the tank at the end of the experiment contained 7.7 per cent of solids. Sludge drawn during the period of the experiment had a solids content considerably higher. At the end of the experiment the sludge contained 40 per cent ash, dry basis. The average of the solids content of the incoming fresh material was slightly below 5 per cent with an ash content of 22–23 per cent.

Due to the process of liquefaction the amount of gas produced during the first part of the experiment was comparatively low. Methane production during the entire period of the experiment fluctuated between 58 and 82 per cent with an average of about 72 per cent; CO_2 varied from 16 to 32 per cent with an average of 24 per cent.

Due to spasmodic additions of fresh solids which were not added every day, the amount of lime necessary was approximately double what it should have been. The amount of lime required per cubic foot of sludge was 71 grams.

CHAPTER XXV

GAS COLLECTION AND UTILIZATION

SYNOPSIS

1. Description.—All sludge digestion chambers require venting. Escaping gases, in some cases, have caused trouble from odors. The collection of the gases prevents their escape into the atmosphere. This is an important preventive step in sewage disposal practice. The gas thus secured as a byproduct in quantities explained in Chapter XXI has advantages through its heating and lighting value and can be utilized in various ways.

2. History and Extent of Use.—In an incidental way sludge digestion gas has been collected and used in one way or another for years. Perhaps the first experience was at Exeter, England, where gases from covered single-story tanks were used for street and Austin, Tex. James used gas to operate an engine in 1907 at Bombay. At Birmingham Eng. a 32-horsepower engine has so operated since 1921. Kessener secured a German patent in 1914 and in Great Britain a patent was issued (111401, Feb. 27, 1917) to Flicker, Parramatta, for the utilization of gas from sludge digestion through aeration and heating of sewage. In the Ruhr district Imhoff for several years has collected gas from various two-story septic tanks. All the new German sludge digestion plants, as well as the Zurich plant, provide for gas collection. At New Castle, Pa., two-story tanks now under construction (1926) will have arrangements for gas collection, and at Decatur, Ill., two-story tanks are also so provided.

3. Calorific Value.—This ranges ordinarily from 7000 to 9000 calories per cubic meter at 0° C. and 760 millimeters. Sometimes it drops to 4200. Erfurt data showed 5600 calories per cubic meter or 630 B.t.u. per cubic foot. Blunk and Sierp data at Essen range from 780 to 1010 B.t.u. per cubic foot.

4. Methods for Utilization.—Various methods have been proposed, as follows:

(*a*) Lighting buildings or streets.
(*b*) Heating buildings, especially at the works.
(*c*) Heating at incinerator plants.
(*d*) Operating internal combustion engines.
(*e*) Steam production by use under boiler, with or without fuel, such as oil.
(*f*) Sale to city gas works.
(*g*) Heating sludge.

5. Advantages.—The collection of gases makes it possible to control and eliminate odors, to recover byproducts and, incidentally, to avoid overflow and incomplete digestion of scum, as already explained in Chapters XXIII and XXIV.

6. Present Status.—Present indications are that this byproduct will be recovered in order to guard against odors and to provide for utilization as noted above, because it has a value for use in excess of the cost of its collection. More and more plants are being equipped with collectors in this country and abroad.

HISTORICAL DEVELOPMENT

Dunbar refers as far back as 1912 to the utilization by Cameron of gases produced in septic tanks for the lighting of street lanterns in Exeter, England. There are also one or two minor examples of where such gases were used some years ago for the operation of small motors or engines at sewage disposal plants in England, Germany, India and Australia. Horace Flicker, for example, patented such a process in New South Wales, Australia, in 1911 (Australia Patent 1654) and later a further patent (British Patent 111401) was issued, which, it is believed, is now held by the Septic Gas Company of Australia. The earliest record of gas utilization is by James in 1907, who used the gas from closed treatment tanks to drive an engine at the Matunga Leper Asylum at Bombay.

Kessener of Holland recognized the possibilities of utilization of such gases in German Patent 290126 of Feb. 7, 1914, in which he described in considerable detail the methods of seeding and developing sludge for maximum gas production. He also pointed out practical applications of such procedures for various trade wastes, such as from paper and starch industries. He recognized at that time the importance of temperature regulation, food for biochemical reactions and the necessity for ade-

quate seeding with appropriate bacterial life in order to avoid excessive production of hydrogen and nitrogen.

The delay in making use of such gases upon a practical scale probably had many causes. With the use of plain sedimentation tanks of large surface area the cost and difficulty of proper gas collection probably prevented any serious consideration of such recovery. It was only after the development of relatively deep sludge digestion chambers of the Emscher tank type and tanks for separate sludge digestion that it became feasible to introduce gas collection and usage in more or less economical fashion. Even then, as now, engineers feared the difficulties which might be encountered by covering a sludge digestion chamber with an air-tight cover, because they felt that safety of operation rather than gas collection should be carefully provided for. It was soon demonstrated, however, that the covering of sludge digestion chambers with covers extending below the water level did not result in any undue danger in operation. Such devices have been developed to a relatively successful degree and a brief description of them will be noted further in this chapter.

CALORIFIC VALUE

The heat value of gas produced as a result of sludge digestion varies usually from 7000 to 9000 calories per cubic meter at 0° C. and 760 millimeters. The variations are principally due, and inverse, to the content of carbon dioxide. The high heat value, of course, results from the content of methane. Actual measurements, by means of the Junker Calorimeter, have been carried out by Blunk and Sierp at Essen for a considerable period of days. These figures show between 780 and 1010 B.t.u. per cubic foot.

The gas produced at Essen has a higher heat value than the city gas, as pointed out by Imhoff, for the city gas contains only 4200 calories, most of which are principally due to hydrogen. Most investigators assume that the heat value of sludge digestion gases will vary in the neighborhood of the amounts noted above, although Strassburger has estimated a calorific value at Erfurt, Germany, of only 5600 calories per cubic meter or 630 B.t.u. per cubic foot.

For purposes of comparison with other forms of gas ordinarily used, Tables 58 and 59 are included.

TABLE 58.—COMPOSITION AND HEATING VALUE OF COMMERCIAL GASES*
(Per Cent Composition)

	Oil gas	Coke oven gas	Carbureted water gas	Water gas	Blast furnace gas	Pintsch gas
Hydrogen (H_2)	32.0	50.0	40.0	48.0	1.0	12.4
Methane (CH_4)	48.0	36.0	25.0	2.0	....	45.4
Ethylene (C_2H_4)	16.5	4.0	8.5	....	....	35.7
Nitrogen (N_2)	3.0	2.0	4.0	5.5	60.0	3.0
Carbon monoxide (CO)	....	6.0	10.0	38.0	27.5	0.6
Oxygen (O_2)	0.5	0.5	0.5	0.5	....	2.0
Carbon dioxide (CO_2)	....	1.5	3.0	6.0	11.5	0.7
B.t.u. per cubic foot	846	603	575	295	91	1500

* Marks, Mechanical Engineers Handbook, 1916 Edition, p. 613; authority, S. S. Weyer.

TABLE 59.—COMPOSITION AND HEATING VALUE OF NATURAL GASES IN THE UNITED STATES

Gas	Constituent								
	(A)			(B)			(C)		
	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.
Methane (CH_4)	79.80	99.20	32.30	72.45	97.60	2.00	77.45	94.70	14.33
Ethane (C_2H_6)	17.29	67.00	0.00	22.15	91.10	0.00	2.83	5.00	0.00
Carbon dioxide (CO_2)	0.41	6.50	0.00	2.01	30.40	0.00	0.41	1.94	0.00
Nitrogen (N_2)	2.48	8.90	0.00	3.28	13.60	0.90	18.47	82.87	2.60
Oxygen (O_2)	......	......	......	0	0	0	0.19	0.50	0.00
Ethylene (C_2H_4)	......	......	......	......	......	......	0.91	10.31	0.00
Helium (He)	......	......	......	......	......	......	0.46	1.64	0.08
B.t.u. per cubic foot at 0° C. and 760 millimeters pressure	1174	1591	1010	1183	1766	724			

(*A*) Data of 31 cities. Technical Paper 158, U. S. Bureau of Mines. Kent's Handbook, 10th Edition, p. 893.

(*B*) Data of 27 localities, G. A. Brinnell, Nat. Gas Assoc. of America, May 1914 (2 cities omitted as very abnormal). Taken from Marks, Mechanical Engineers Handbook, 1916 Edition, p. 614.

(*C*) Data of 37 samples taken from seven localities by Cady and McFarland (University of Kansas). Stillman's Eng. Chemistry, 1916, p. 677. NOTE.—These figures show an abnormally high nitrogen content due to the inclusion of a Kansas district running high in nitrogen.

COLLECTION OF GASES

The collection of gases from any type of sludge digestion chamber, whether of the two-story Emscher design or separate sludge digestion tank or any modifications of plain settling tank with small digestion area, may be accomplished at relatively slight cost with simple construction details. The expense of

accomplishing this result naturally varies with the size, shape and purpose of the tank as originally installed. It is likewise true that reconstructing an existing tank for gas collection purposes, which was not so designed as to provide for this recovery, usually involves more cost than if the plant were originally designed for gas collection before it was built. Since the process of gas utilization is practicable and feasible, this element of sewage treatment should always be kept in mind when designing containers for sludge digestion, so that advantage may be taken of

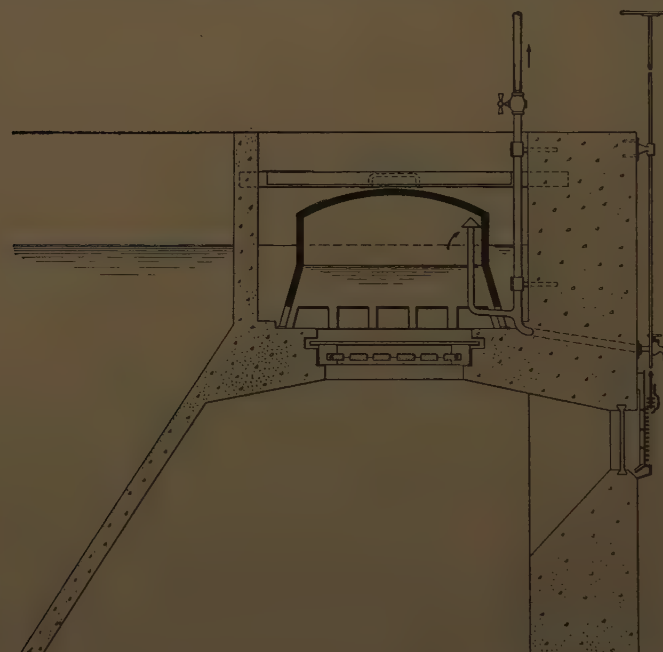


FIG. 41.—Cover and gas trap for two story tanks.

the recovery of gases at minimum cost for installation of gas collectors.

The exact designs for gas hoods and collectors, with piping systems, for transmission of the gas to the point of usage, differ in certain details in different plants. In each instance, however, the digestion chamber is sealed under water by a reinforced concrete or metal cover in which there is retained a relatively small opening for the passage of gas. Above this opening a gas hood is placed so as to lead the gas to the outlet. Between the

reinforced concrete or metal cover and the gas hood a free space is left. Under the hood is a wooden separator built up of tongue and grooved framing, in which groove openings permit lateral escape of gas around the ends of the tongued paneling, in order to prevent the scum in the sludge chamber from passing up into the hood and clogging the gas outlet. Either the natural hydrostatic pressure or an artificial pressure may be provided to give the necessary head to pump the gases to the point of utilization. The frequency of removing the scum screen and the hood for cleaning purposes depends entirely on the local conditions.

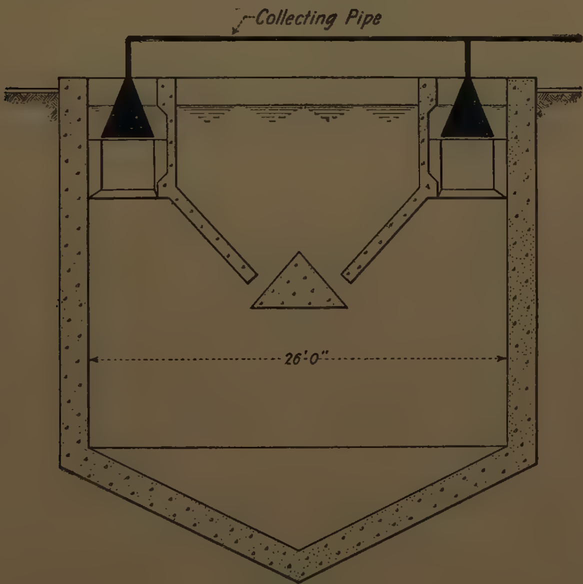


FIG. 42.—Gas hoods and piping.

At the head of each hood, valves and sampling cocks are provided in order to permit testing the nature and quantity of the gas. Likewise devices for metering the gas produced are usually installed.

In order that these details may be clear, Figs. 41 and 42 are presented as typical installations of gas hoods and piping in a two-story tank.

Further details and photographs of actual installations are shown later in this chapter where examples of gas utilization are discussed at greater length.

UTILIZATION

Opportunities for utilization of gases present themselves to those who have been interested in developing this field. These opportunities differ, depending upon whether the gases are used in a raw state or whether they are subjected to some form of purification.

In the raw state gases may be led directly into the gas distribution system of municipalities where the municipal gas plant or its distribution system is close to the sewage treatment plant. Connection with the municipal distributors is simple. Actual examples of such usage, particularly in Germany, will be noted later.

Where such purchase by gas plants is not feasible, it has been suggested that the gas be compressed into cylinders so that it may be transported for lighting and heating purposes to isolated houses, factories or laboratories. Some of the gas may be used for compressing the remainder to be made available for sale. The gas in its raw form may likewise be used as a fuel for driving engines. Here again several practical installations have been in operation for a considerable period of time. In many instances, however, it would appear more feasible to use the gas for the generation of steam, with provision for supplementary fuel, instead of direct use of the gas as a fuel in the engine. The use of gas for steam generation offers more flexibility.

It might be pointed out that ordinarily the gas is worth more as gas for domestic lighting and heating purposes than it is for power or fuel at the plant. In other words gas is an expensive source of power.

Gases are purified to produce as high a percentage of methane as possible. This involves a removal of carbon dioxide and hydrogen. The hydrogen may be eliminated by passing the gas through nozzles through the bottom of the sludge chamber. In this way it has been shown that a gas with a hydrogen content of 18.1 per cent may be reduced to one showing no hydrogen. Carbon dioxide may be removed by treating the gas with milk of lime or by passing it under pressure through clean water. By this means the CO_2 content of the gas may be reduced to 0.5 to 2 per cent, depending upon the content of the raw gas. Such resulting gases may be used for autogenous welding and cutting.

The methane may also be chemically converted, as shown in the Plausson patents, to hexamethylentetramin, used as an

"accelerator" of vulcanization and in the preparation of artificial phenol resins, such as bakelite and redmanol. Certain halogen substitution products may be obtained also from methane as described in patents in the literature.

EXAMPLES

Under proper conditions of operation, involving the addition at regular intervals of fresh sludge to considerable portions of digesting sludge and with due precautions for proper seeding, Imhoff[1] expects to obtain in the sludge digestion chamber of a normal municipal treatment plant annually for each contributor to the sewerage system about 3 cubic meters per year or about 8 liters per capita per day. A somewhat greater amount will be produced in the summer and a somewhat smaller amount in the winter. He assumes that in a year's time a quantity of gas may be produced equal to 0.3 cubic foot per capita per day. For a city of 100,000 inhabitants, therefore, he would anticipate the production of 11 million cubic feet of combustible gas per year. As already mentioned, this quantity will be developed provided the amount of new sludge brought to the tank is sufficient to carry on continuous gas production. According to Rudolfs and Baity these figures may be more than doubled under suitable control.

Activated Sludge Digestion.—The digestion of sludge from the activated sludge treatment process[2] offers certain interesting departures from the principles outlined above which should be kept in mind when provisions for gas utilization from the digestion of activated sludge are under consideration. The gases which result from the decomposition of activated sludge are practically of the same composition as those from ordinary sewage sludge, provided, however, the activated sludge has been thoroughly inoculated with digested sludge. This and other aspects of disposing of activated sludge are discussed in Chapter XXXIX. The quantity of gas usually derived from preliminary two-story tanks, according to Imhoff, amounts to 8 liters or 0.3 cubic foot daily per capita. This quantity is doubled by the excess of activated sludge; that is, it is increased to 16 liters or 0.6 cubic foot of gas per capita. (See Fig. 43.) Imhoff further claims that the power content in this quantity of gas is

[1] Eng. News-Record, Sept. 27, 1923.
[2] Eng. News-Record, June 4, 1925.

so large that it probably would suffice for the working of the aerating tanks. These gas quantities are much smaller than given by Rudolfs and Baity as stated in Chapter XXI.

A brief summary of the actual installation of systems for the utilization of gas from sewage sludge digestion is noted below.

GERMAN EXPERIENCES

Erfurt.—Strassburger proposed installing a plant in 1923 for the recovery of marsh gas to be used in heating a neighboring hospital. His design is based upon the results of a small experimental installation in which the beneficial effects upon gas production of a temperature of 25 to 35° C. (77 to 95° F.) were fully investigated. The experimental results showed that with a

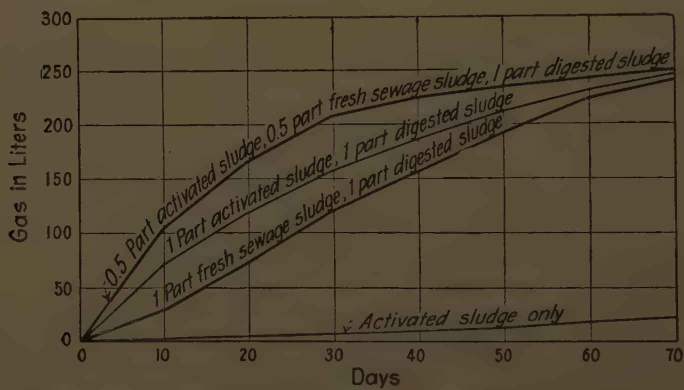


FIG. 43.—Gas produced from 1 kilogram of organic matter kept at 17° C.

temperature of 26° C. (78.8° F.) the maximum rate of production of gas was attained in 43 days, and amounted to approximately 2 cubic meters (70.6 cubic feet) of gas per hour per cubic meter of sludge, decreasing gradually to zero at the end of 3 months, the resulting total production being 260 cubic meters (9182 cubic feet) of gas per cubic meter of sludge. With a temperature of 35° C. it is anticipated that similar results will be attained in 2 months. During the process the sludge is reduced to two-thirds of its original bulk.

The plant designed for Erfurt consists of a covered circular tank, 35 meters (114.8 feet) diameter, divided into four quadrants with cone-shaped bottoms, and having a center compartment in which is installed the mechanical plant, consisting of

motor-driven air compressors, ejectors, heating coils, piping, etc. The necessary temperature is maintained through slow circulation of the contents of the tank by means of compressed and warmed air with which the sludge is brought into contact. The volume of air thus used is approximately 1 cubic meter per cubic meter of sludge. The capacity of the tank is 7000 cubic meters (247,209 cubic feet), representing about a quarter of the present yearly quantity of sludge from a population of 135,000, with a yearly dry weather flow of 7 million cubic meters (247.2 million cubic feet). The estimated production of gas available for external heating purposes is 400,000 cubic meters (14,126,200 cubic feet) per annum, with a calorific value of 5600 calories per cubic meter (630 B.t.u. per cubic foot).

Essen-Nord.[1]—On the average, 3000 cubic meters of sludge were under digestion in the sludge chamber. The average water content of the sludge was 93.5 per cent, so that there were 6.5 tons of dry matter in 100 cubic meters of sludge. In total, therefore, there was available for production $\frac{6.5 \times 3000}{100}$ or 195 tons of dry substance. In a period of 10 months, from Oct. 1, 1923 to July 31, 1924, approximately 150,000 cubic meters of gas were produced, the equivalent of 500 cubic meters of gas per day. On the basis of 195 tons of dry material, therefore, 2.5 cubic meters of gas were produced per ton at an average temperature of 17.5° C. Since there was about half organic material in the dry substance, approximately 5 cubic meters of gas were produced per ton of organic content. In the normal operation of the Essen-Nord plant about 600,000 cubic meters of gas are developed annually. A part of this gas, before the industrial situation in the Ruhr district was disturbed, was purified in a separate installation or treatment plant so as to produce pure methane.

Essen-Frohnhausen.[1]—In the winter of 1922–23 gas measurements in the separate sludge digestion chamber were carried out. In this case, temperature conditions in the sludge digestion chamber were not of the best. The water content of the sludge was 86.3 per cent with approximately 62 tons of dry material in the sludge space. From Dec. 8, 1922 to Jan. 31, 1923, a period of 54 days, 3400 cubic meters of gas developed at an average temperature of 7.5° C., or about 1 cubic meter of gas per ton

[1] Emscher-Genossenschaft, 25 years' Experience.

of dry material per day. Further observations at lower temperatures showed still lower gas production.

Essen-Rellinghausen.—At this plant the two-story tanks have been equipped with gas catchers on the entire plant since 1922. The gas catchers are provided with wooden covers and the gas is sold to the city gas works at 3.5 pfennigs per cubic meter of gas. The plant is now handling the sewage of approximately 45,000 people. A total annual production of 120,000 cubic meters of gas is noted by Blunk and Sierp.

Kettwig.—The gas from a small plant of two-story tanks, providing for 8000 people, is used in the homes of the operators for lighting and heating purposes.

Hagen.—A plant for 85,000 people is provided with two-story tanks. Half of the tanks are equipped for gas collection and the gas is used by neighboring farmers, inasmuch as no center of population is nearby to which to sell. The plant is of a design which is not favorable for gas collection, but, even with these disadvantages, equipment is installed which is working adequately.

Stuttgart.—The engineer for Stuttgart, Sohler, has established through experiment that, in the digestion of the settled sludge at his plant, 10 liters of gas per person per day are obtainable with a heat value of 6500 to 7000 calories per cubic meter. In a year, therefore, he hopes to obtain approximately 1 million cubic meters of gas from a population approaching 250,000 people per cubic meter. He has contracted with a neighboring municipal gas works for the sale of gas produced at 8 pfennigs per cubic meter or approximately 80,000 gold marks per year. The municipal gas works in turn has contracted to sell this gas to a neighboring municipality at 25 pfennigs per cubic meter. Sludge chambers of all the settling basins are now (1926) in process of being covered, in order to collect and sell all gas evolved in sludge digestion. The gas will be brought to the city gas works through a pipe line 9 kilometers long and will there be mixed with the rest of the artificial gas. As the sludge digestion chambers were not designed for gas utilization, the cost of covering them is naturally much greater than if the gas recovery had been borne in mind when these basins were originally constructed in 1916.

Sohler is planning to use, as a preventive of scum interference with gas collection, a porous reinforced concrete plate just below the gas collectors, in place of the wooden separator sug-

gested and used by Imhoff. The type of cover being built is shown in Fig. 44.

Munich.—Keppner is now (1926) constructing gas collectors over the sludge digestion compartments for the recovery of gas. These covers are of reinforced concrete and are hemispherical in form. They are slotted to provide for the flow of water through and above them, but are so baffled as to prevent the entrance of gas into the water over-lying the hood. The gas hood is protected

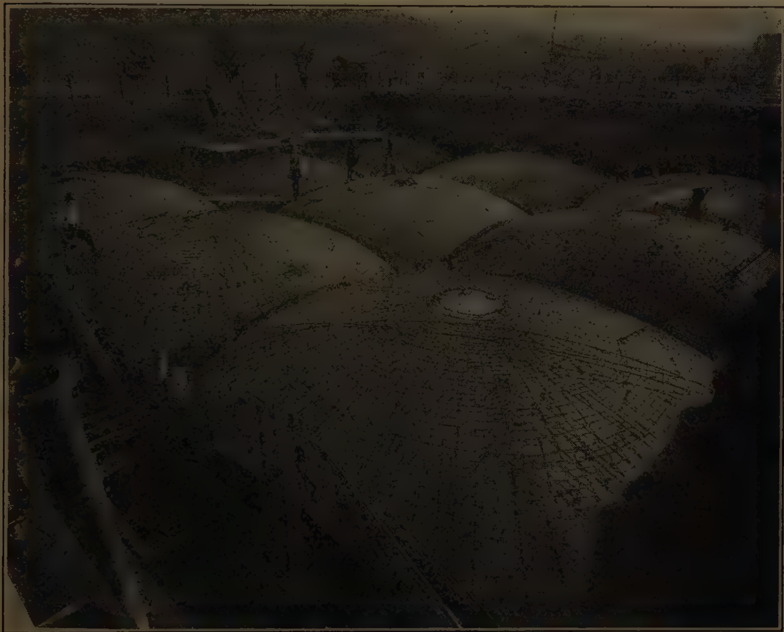


Fig. 44.—Construction for gas collection on Neustadt tanks, Stuttgart.

against floating scum by the use of wooden covers or separators such as in the Imhoff installations. Keppner expects to obtain about 10 liters per person per day and to sell the gas to the city gas works at a probable charge of 10 pfennigs per cubic meter. The population contributing to this plant is approximately 500,000.

Zurich, Switzerland.—The Zurich plant has been in operation since July, 1925, and is at present serving a population of about 40,000. A gas collector has been constructed on one unit of the sludge chamber, but all of the tanks are so designed as to provide

for ultimate gas collection. The scum protectors have not yet been installed and no decision has been made as to the choice of wood or porous concrete for these scum separators. The City Engineer, Bosshard, expects to obtain about 5 pfennigs per cubic meter from the sale of the gas to the city gas works. He anticipates about 3 cubic meters of gas per year per capita or a total of approximately 600,000 cubic meters for the present population of Zurich, namely 200,000.

BRITISH EXPERIENCES

Birmingham.—The utilization of gas at Birmingham is of special interest because it represents one of the few large separate sludge digestion plants in which gas collection and utilization have been tried. So successful has the recovery been that Whitehead, their engineer, is now installing (1926) equipment on the large separate sludge digestion chambers at the Saltley Works for the collection of gas to operate a 150 horsepower gas engine.

Since September, 1921, the gas obtained from the fermentation of sewage sludge has been used at the Colehall works of Birmingham to drive a 32-horsepower gas engine. Although the estimates of gas volumes anticipated at this plant had to be reduced somewhat, because of variations in rates of gas production in winter and in summer, the observations on quantity and quality of gas produced during the past 3 or 4 years have warranted the authorities in contracting for the installation of a 150-horsepower gas engine. This installation and the necessary equipment on the tanks will probably be completed in the very near future.

Half of two of the preliminary sludge digestion tanks are to be covered. These covers are to consist of floating pontoons about 30 feet square. Each pontoon is provided with a gas dome in the center. The various domes are connected to a gas main by means of flexible piping.

Special tests were carried out at the Colehall Works in November, 1925, to obtain a measure of the total gas generated from a tank containing 94 cubic yards of sludge. The average temperature of the sludge in the tank during the tests was 58° F. The raw sludge when originally added contained 92.6 per cent water. The average yield of gas was found to be sufficient to provide continuously 1.61 indicated horsepower. On this basis

the indicated horsepower hours available per week would be $1.61 \times 168 = 270$.

The composition of gas produced, on the basis of analyses extending through 3 years, showed on the average:

	Per Cent
Methane	67
Carbon dioxide	30
Nitrogen	3

At the Saltley works the quantity of sludge from which gas will be collected is approximately 10,750 cubic yards. Whitehead states that the total length of four gas collectors which are proposed will be 480 feet. He estimates from the observations at the Colehall works over the period Oct. 1, 1924, to Oct. 1, 1925, that 94 cubic yards yielded 10,050 indicated horsepower hours during the year. On this basis, the estimated amount of power obtainable from the 10,750 cubic yards of sludge at the Saltley works will be 1,150,000 indicated horsepower hours per year or 22,100 per week.

Special tests run at the Colehall works during November, 1925, indicated that 94 cubic yards of sludge were capable of providing 270 indicated horsepower hours per week under the conditions then prevailing. On this basis the amount of power to be expected from the 10,750 cubic yards of sludge at the Saltley works will be 30,900 indicated horsepower hours per week, assuming conditions are the same as at the Colehall works at the time of the test.

Bristol.—The Septic Gas Company of Australia, Ltd., has built a plant near Bristol, England, for the recovery of gas on a working scale. The details as to quantity of gas and of sewage are not available.

Parramatta, New South Wales, Australia.—Walshaw describes a treatment plant in Parramatta for 13,000 people producing gas of the following composition: 14 per cent CO_2, 1.1 per cent oxygen, 60 per cent methane, 8 per cent hydrogen, 16.9 per cent nitrogen with a heat value of 5340 calories per cubic meter.

The installation is described in the Engineer, Dec. 23, 1921, p. 669.

Brisbane, Australia.—Since 1914 a pump has been driven by a 17-horsepower gas engine using the gas produced in the sewage treatment plant for a population of 13,000.

Lithgow, Australia.—The details of this gas utilization plant are not available.

AMERICAN EXPERIENCES

Atlanta, Ga.—At Atlanta in 1915 galvanized iron covers were placed over 3 out of 30 gas vents of the Imhoff tanks and the gas was collected into a small gas holder from which it was piped to the laboratory and residence where it was used successfully as fuel in laboratory burners, heating stoves, cooking stove and hot water heater.

Hommon, in describing this installation,[1] gave the following composition of the gas collected:

	Per Cent
Methane	84.1
Nitrogen	3.1
Carbon dioxide	4.6
Oxygen	0.4
Hydrogen	8.6

The calorific value was given as 700 B.t.u. per cubic foot. The installation has since been abandoned.

Austin, Tex.—At Austin, Tex., where operation of Imhoff tanks resulted in litigation against the city on account of offensive odors to nearby residences, devices have been installed to eliminate the complaint by burning the gases. The vents of the Imhoff tanks have been covered and the gas is removed by a small motor driven pump which delivers the gas as it forms to a brick stack where it is burned. Nuisances have thereby been eliminated and a portion of the gas is used in winter time to heat the sewage pumping station. It has also been suggested to use it at the garbage incinerator. A description of the installation has been given by Leonard in Eng. News-Record, 1922, Vol. 88, p. 565.

Decatur, Ill.—This plant treats considerable starch wastes in the municipal sewage. About one-tenth of the total sludge area of the Imhoff tanks was capped in October, 1925. The sewage flow is about 13 million gallons per day from an equivalent population of 300,000. The biochemical oxygen demand of the raw sewage varies from 700 to 900 parts per million. The estimated amount of gas produced per day has varied from 30,000 to 200,000 cubic feet. The average winter temperature of the sewage varies between 70 and 80° F. With cold winter rains or thaws the temperature drops to 60° F. In summer the temperature of the sewage is 100° F. The gas shows 60 to 80 per

[1] Eng. News-Record, 1916, Vol. 73, p. 182.

cent methane and 900 to 950 B.t.u. per cubic foot. The gas is used for heating the laboratory and office building. It contains about 1 per cent hydrogen sulphide. The collector was installed to prevent odors. Hatfield estimates that about 14 cubic feet of the gas will generate 1 brake horse power per hour in a combustion engine.

Larchmont, N. Y.—At Larchmont gas and air are withdrawn from the top of separate sludge digestion tanks through a cast-iron main connected with a motor-driven exhauster which discharges into a 125-foot stack. Provision has been made to chlorinate this gas, if it is found to be necessary. These arrangements were installed in order to avoid nuisances from odors, since the plant is located in a good residential district. The works were built in 1925.

PRESENT TREND

Sufficient experience has been accumulated in the course of the last 15 years to indicate that the collection and utilization of gas in the digestion of sewage sludge are practicable procedures. The economy of so doing is naturally dependent upon the usage to which the material is put. The German experience has shown that the construction cost for gas-collecting apparatus, including the piping on the disposal plant grounds, amounts to only 1 per cent of the cost of constructing an Imhoff tank plant. In the Ruhr coal districts where the gas is delivered to the municipal gas plant, the price paid by the city amounts to two-thirds of the cost of the ordinary municipal gas. In spite of this low price the receipts cover half of the total operation costs of the Imhoff tanks. As the price paid by the city is still much too low in comparison with the calorific value, Imhoff assumes that the price will later be raised so that the entire operation cost will ultimately be covered. A still higher return from gas sale is anticipated as the result of conferences with chemical works in Germany which may offer an outlet for the delivery of gas for special scientific purposes.

Whitehead at Birmingham suggests that it is profitable to install and operate gas-collecting systems on the separate sludge digestion tanks, when the operating cost of producing power for the engines is approximately half of the power charges which he would have to pay to private utilities in the vicinity of his plant.

In Germany the selling price or value of the collected gases is dependent upon and regulated by the existing prices of coal. The German engineers, therefore, calculate the possibilities of economic return upon gas collection by referring their interest, sinking fund and operating charges for gas collection to the existing price of coal.

Considerable emphasis should be placed upon the economic aspects of gas collection and utilization from sludge digestion. This offers almost for the first time some means of recovering a byproduct and producing a revenue in a sewage treatment process. This aspect of gas utilization cannot be overstressed. Present evidence suggests equipping all plants for sewage sludge digestion with gas-collecting apparatus, not only at those plants where there is need for the gas itself, but where gas may be conveniently delivered to municipal mains or where it may be profitably sold to neighboring chemical plants. Where the conservation of capital expenditure and reduction of operating charges is, as it nearly always is, a prime desirability, recoverable values in the normal operation of sewage treatment plants should not be permitted to escape unused into the atmosphere.

In addition to the economic utilization of such gases, it is still more important to provide for their collection and disposal in order to prevent the dissemination of objectionable odors sometimes associated in the past with sludge digestion.

CHAPTER XXVI

DISPOSAL OF DIGESTED SLUDGE

1. Classification.—This chapter deals with the disposal of sludge which has been digested in tanks. Disposal of undigested sludge and of sludge produced by the activated sludge process is treated in Chapters XX and XXXIX.

2. Method of Disposal.—In this country, as well as in Germany, it is now customary to dispose of digested sludge, whether from single-story, two-story or separate digestion tanks, upon specially prepared drying beds of gravel or slag covered with a thin layer of sand. Until the introduction of Imhoff tanks in this country, however, the sludge from septic tanks was disposed of on land either by lagooning or trenching or upon ordinary sand beds similar to sand filters. Digested sludge is sometimes, though not frequently, used for fertilizer.

3. Nature of Sludge.—Well digested sludge is black and somewhat gelatinous, and usually has a tarry odor. Under favorable conditions it contains about 15 per cent of solids, and sometimes as much as 20 per cent. Sludge which has been digested for a long time, such as that drawn from tanks after the winter season, is generally denser than that drawn later. Under unfavorable conditions, particularly where the sludge has not been sufficiently digested, it may contain as little as 3 to 7 per cent of solids. Another outstanding characteristic of sludge is its content of entrained gases, which control to a considerable degree its drainability through causing the solids gradually to rise above the underlying water. Rudolfs states that a well digested sludge should have a biochemical oxygen demand, at 20° C. for 24 hours, of not over 1000 parts per million for each per cent of organic matter in the sludge; and that with a corresponding figure of 1500 parts sludge is stable enough to be drawn under ordinary circumstances. The material should have a pH value higher than 7.0, usually 7.4 to 7.8.

4. Construction of Drying Beds.—Sludge drying beds usually have an average depth of about 12 inches, and are composed of

sand and gravel of graded sizes. Greater depths are sometimes used, though seldom more than 18 inches. In some beds a very thin layer of sand, $\frac{1}{4}$ to $\frac{1}{2}$ inch, is used at the top; in other cases depths of 2 to 6 inches of sand are used. Beneath the sand several layers of screened gravel or broken stone are placed; the upper layer being sometimes as fine as $\frac{1}{16}$ to $\frac{1}{4}$ inch, and the remaining layers of gradually increasing sizes, up to perhaps 1 to 2 inches. Underdrains are provided, except in cases where the soil beneath is quite porous. Underdrains are of vitrified pipe, laid with open joints and surrounded by gravel, spaced from 6 to 15 feet or more apart. Beds are usually surrounded by light concrete walls, and large beds are divided into compartments by means of partitions of concrete or wood. Compartments are frequently about 20 feet wide, and generally not more than 100 feet long, particularly where they are fed from one end.

5. Covered Beds.—Beds covered with glass in a manner similar to greenhouse construction have been used at a few places in this country, as at Canton, Alliance and Marion, Ohio; and Highland Park, Ill. The latest example of this construction is at Boonton, N. J., a photograph of which is shown in Fig. 45. The purpose is to increase the number of fillings during the warmer season by preventing interference with drying during wet weather, and also to permit sludge to be drawn to some extent during the 5 colder months of the year. An incidental advantage is that the appearance of the plant is improved by hiding from view the large areas of sludge in the process of drying. Although evaporation is somewhat interfered with, the required areas may be reduced to about one half of what would be needed with open beds. Browne and Jones in a paper before the N. J. Sewage Works Association in 1926 claim from their Ohio experiences that covered beds need be only one-third that of open beds. They indicate that covering costs about $1.60 per square foot while the bed with industrial track costs about $1.00, an apparent economy for covered beds.

6. Area Required.—The area required for sludge drying beds depends upon the population connected, upon whether the sewage is separate or combined, upon the character of the trade wastes, if any, in the sewage, upon the climate with respect to the duration of warm weather and the amount and distribution of rainfall, and upon the character of the sludge as regards digestion and water content. Early practice in this country was to provide

an area of $\frac{1}{3}$ square foot per capita for domestic sewage dried on open beds; but in some cases, particularly where the sludge was not well digested, this allowance has proved insufficient. When the sludge has been well digested in deep tanks, an area of 0.5 to 1.0 square foot per capita should be sufficient for plants treating separate sewage, depending upon the climate, although considerably more has lately been allowed in order to provide against possibility of having to treat partially digested sludge at times. An addition of 50 per cent or more, however, should be made in the case of combined sewage and of as much as 100 per cent if trade wastes containing abnormal amounts of solids are present.

FIG. 45.—Glass-covered sludge drying beds, Boonton, N. J.

If covers are used the areas may be reduced to one-half of those stated and Browne and Jones suggest that a reduction to one-third may be justified.

7. Application to Beds.—In northern climates in this country it is customary to apply sludge to drying beds from six to ten times per year. No sludge is drawn from the tanks during the cold season. In the Ruhr district in Germany, about 12 doses per year are applied. Usually doses are from 8 to 12 inches in depth. The covered bed at Alliance for the years 1921 to 1923, inclusive, average 19 fillings per year, with doses averaging 6 inches deep. At Stuttgart, Germany, several layers of wet sludge are applied in succession, as soon as the underlying layer has dried, as it has been found that the dried sludge has sufficient filtering capacity

through its cracks to permit prompt and adequate drainage of the next layer. Sludge is discharged to the beds through channels or pipes by gravity where possible. Pumping, particularly by centrifugal pumps, is objectionable, because it tends to liberate entrained gases and thus render the sludge less porous. Pneumatic ejectors are frequently used for this purpose. The sludge will readily spread to a practically uniform thickness over the bed for a distance of 50 feet; and distances of 100 feet or somewhat more permit fairly uniform distribution with the more liquid sludges.

8. Period of Drying.—The solids in the applied sludge are floated to the top on account of the gas that is entrained in them. Much of the liquid filters down through the bed. In dry weather, with open beds, the sludge, if well digested when applied, becomes spadable in about 10 days. In wet weather the required time is much longer. With poorly digested sludge more than 2 weeks may be necessary, even in dry weather during the summer.

9. Alum Treatment.—In order to produce quicker drying, treatment of the sludge with alum has been tried at Plainfield, N. J., where the sludge has at times been poorly digested. By applying a solution of alum to the sludge as it enters the beds, at a rate of 1⅓ pounds of alum per cubic yard of sludge, the number of dryings per bed in 7 months was increased from 6 to 11. With well digested sludge of low water content this treatment was not found necessary. At Schenectady, similar treatment was not found helpful.

At times it may become necessary to draw off sludge which is not fully digested, in order to prevent or reduce foaming in the sludge digestion tanks. Under these circumstances, odors are likely to occur, and the use of chloride of lime may be helpful in controlling them.

10. Removal from Beds.—The dried sludge is porous, somewhat resembling garden soil, has practically no odor, and has a water content of about 60 per cent or less. It is readily removed by means of spades or forks, taking with it a small amount of sand from the top of the bed, and requiring replacement of this sand sooner or later, depending on the thickness of the top layer. In small installations, and sometimes in large ones, the dried sludge is thrown into carts, as shown in Fig. 46, which shows the sludge at Stuttgart, Germany, being taken away by farmers. This was the method of removal at Stuttgart until recently. Now bucket

and belt conveyors operate over the entire area of the beds. These conveyors clear the beds very rapidly and dump the sludge upon an unloading platform at the end of the belt con-

FIG. 46.—Removal of sludge from sludge drying beds, Stuttgart.

FIG. 47.—Sludge removal equipment, Rochester, N. Y.

veyor. At many plants, industrial tracks, either permanent or portable, are laid in the beds, and the sludge is taken away in cars. At Rochester, N. Y., as shown in Fig. 47, the dried sludge is thrown into dump buckets, which are picked up by a traveling crane and placed on cars running on a central track.

11. Disposal of Dried Sludge.—Dried sludge may be used for filling or for fertilizing purposes. For fertilizing, it is preferable to fresh sludge, as it promotes porosity of the soil and does not develop weeds. At Plainfield, N. J., oats and corn have been profitably raised directly on spadable sludge placed over sandy soil. At Dallas, Tex., it was found that surface soil which has been fertilized by ploughing in dry sludge does not pack and crack under the action of the sun as badly as in areas not so fertilized. The growth and appearance of corn so fertilized was much improved.

In this country, dried sludge is frequently given to farmers. At Baltimore, about one half of the dried sludge produced is loaded by the city upon the farmers' trucks and removed by the farmers. In Germany, farmers frequently pay for the dried sludge. Attempts have been made to utilize the sludge, after heat drying, as a base for fertilizer, but without marked success.

Systematic efforts have been made recently in several localities to develop a market for air dried sludge. In 1925 at Schnectady farmers removed from sludge beds about 1200 cubic yards, saving about $200 in labor and team hire. After improving the loading facilities it is estimated that in 1926 there will be a revenue of $100. In the North Shore Sanitary District (Ill.) a farmer pays $200 per year for the privilege of cleaning the drying beds serving Imhoff tanks for 5640 population, and removing the sludge.

12. Effluent.—The effluent from the underdrains of sludge drying beds may be non-putrescible, but is rarely free from bacteria. It is discharged at times directly into streams on the score that objectionable bacteria have not survived the digestion process. A safer procedure would be to return this effluent to primary treatment devices.

CHAPTER XXVII

CHEMICAL PRECIPITATION

1. Description.—This method consists in coagulating sewage before its entrance into sedimentation basins with such chemicals as sulphate of alumina, iron persulphate, ferrous sulphate and lime, or lime alone. The purpose is to coagulate and promote the sedimentation of non-settleable and colloidal matters which would not be removed by plain sedimentation.

2. Efficiency.—Chemical precipitation as compared with plain sedimentation will remove total suspended matters, depending upon the freshness of the sewage and the completeness of coagulation, up to a range of 80 to 90 per cent in comparion with say 50 to 70 per cent found in plain sedimentation. Percentages of removal of total organic matter may be increased from 30 to 35 per cent for plain sedimentation up to an ordinary range of 50 to 55 per cent. Bacterial removal will approximate 80 to 90 per cent.

3. Development.—This process was developed in England more than 60 years ago in an effort to separate from the sewage those constituents of value for fertilizing purposes and in the hope of making the method a commercial success. The latter phase did not prove true. The process met with great favor in England as a result of encouraging investigations by Royal Commissions and its adoption for London. Its fame was at its height between 1880 and 1890 when more than 200 plants of this type were installed in England with several notable plants in America and on the continent in Europe.

4. Waning Status.—Several factors contributed to bring about the practical displacement of this process for ordinary conditions. First came methods involving sedimentation and arrangements for handling sludge through the septic process. Then came successful methods for the biological purification of sewage on filters of artificial construction capable of producing a non-putrescible effluent, a result which is not feasible by the chemical precipitation method. Another important factor was the

increased cost of chemicals, particularly during the war period. Mention should also be made of the greatly increased volume of sludge to be disposed of, where chemicals are used. Finally an item of importance was the widespread use of chlorine for disinfecting the sewage, the adoption of which was considered advantageous in connection with plain sedimentation, in cases where it was not necessary to go to the expense of filtration or other arrangements for removing total organic matter to an extent greater than about 30 per cent.

5. Present Status.—Chemical precipitation for plants dealing with ordinary municipal sewage has been practically abandoned and for many years no new plants of this type have been installed. There are cases, however, where chemicals are required for the treatment of municipal sewage receiving unusual quantities of trade wastes. Another field of applicability refers to cases where, during very dry hot weather or during periods of lessened volume of diluting water, plain sedimentation falls temporarily short of requirements, but where ordinarily no more improvement in the sewage is needed than is afforded by plain sedimentation. This has occurred several times at London since 1911 when the regular use of chemicals was abandoned. During 1925 plants at Worcester, Mass., and New Rochelle, N. Y., were abandoned.

Chemical precipitation is still used at the Dalmarnock plant at Glasgow, Scotland. The sewage contains considerable free acid and iron wastes from wire mills which react favorably with lime for precipitation. At the Shield Hall Works in the same city, chemicals are still used, but it is doubtful if their addition will be continued for many more years.

At Salford, England, alumino ferric and lime are still used in conjunction with settling tanks preliminary to trickling filters. Hart, at Leeds, applies iron persulphate to the raw sewage in order to reduce the load on the trickling filters. He considers it of sufficient added value to warrant its continuance.

The application of sulphuric acid to raw sewage at Bradford should not be included as a normal adaptation of chemical precipitation, for here the acid is applied entirely for the precipitation of large amounts of lanolin fat, preparatory to its recovery and sale.

This method may be relegated to the superseded processes, except for special problems which have no place in this volume. However, for those having occasion to investigate the matter, working data are readily available in several works of reference.

CHAPTER XXVIII

ELECTROLYTIC METHODS: DIRECT OXIDATION

1. Development.—For some 70 years repeated efforts have been made to apply electricity in a practical way to the purificas tion of sewage. While one patented process after another has come to the front, no generally accepted method has been developed. Decades have passed with comparatively short intervals between succeeding inventions claiming to have overcome the defects of earlier ones. The possible use of electricity, however, still rates as a fascinating subject in this branch of sanitation. It is such a continuing procession of patents, claims and allegations by inventor and promoter that prompts a brief recital on this general subject for reference purposes.

Electrolytic Process

2. History.—In London about 1890 investigations were made of the Webster process by which current, through electrolytic decomposition of iron electrodes, produced a coagulating chemical. These tests were followed by others in the United States, notably at Louisville where Fuller in 1896–97, in connection with water purification investigations, studied the application of electrolysis through various kinds of electrodes. He found the process had no practical merit in point of efficiency or economy as compared with the coagulating effect to be obtained by the use of commercial chemicals.[1]

3. Plants in Practice.—In addition to numerous testing stations, six or eight plants have been installed in which electrolytic decomposition of iron or aluminum plates was a distinguishing feature. The Santa Monica, Calif., and Oklahoma City, Okla., plants were operated for several years, but, as far as known, all plants of this type have been abandoned, principally because of high cost of operation as compared with the results obtained.

[1] Fuller, Sewage Disposal, 1912.

[2] Eng. News-Record, 1912, Vol. 66, p. 569; and 1920, Vol. 84, p. 135.

Direct Oxidation Method

4. Process.—In this process the effect of electricity upon living and dead organic matter is claimed, as against the coagulating feature of the electrolytic decomposition of iron or aluminum plates. The fundamental claims for the direct oxidation process, as revealed by patents issued to C. P. Landreth, and in publications by him and by his technical advisers, are summarized, as follows:

(*a*) The production of nascent oxygen and hydrogen by electrolysis of sewage previously rendered caustic, preferably with calcium hydroxide; the caustic inducing electrode passivity by the formation of an oxide film, and also acting as a precipitant.

(*b*) Removal of the electrode accretions while producing nascent oxygen and hydrogen by electrolysis with electrodes rendered passive in the previous process, followed by the addition of a caustic precipitant such as calcium hydroxide.

(*c*) Alternate application of the above processes, as occasion demands, to produce nascent oxygen and hydrogen and maintain the electrodes in a passive condition.

5. Action of Lime.—Lime in the form of calcium hydroxide is claimed to serve the following purposes:

(*a*) It supplies the ions which conduct the current and liberate nascent oxygen at the lowest voltage.

(*b*) It removes the majority of the attacking ions by the formation of slightly soluble calcium salts from the free and half-bound carbonic acid, normal carbonates and sulphates, thereby decreasing their concentration.

(*c*) It produces a flocculent precipitate of calcium and magnesium carbonate (hydroxide) which acts as a coagulant.

(*d*) It hydrolyzes some of the organic compounds and converts them into ammonium hydroxide and calcium carbonate.

The current acts as a means of reducing unstable soluble organic matter by the nascent hydrogen into compounds which are later oxidized into nitrates, nitrites, and carbon dioxide by the nascent oxygen. The current attracts colloids to the electrode whose polarity is opposite in sign to the charges of the colloids, and at that point their charges are neutralized by contact. Since these charges supposedly hold colloids in suspension, their neutralization is intended to cause the colloids to agglutinate and precipitate. Agitators are placed between the electrodes of the apparatus and their purpose is described as follows:

(*a*) Keeping the electrolyte passage free from obstruction.

(*b*) Acting as mechanical depolarizers by preventing concentration of the products of electrolysis in the vicinity of the electrodes.

(*c*) Insuring intimate contact of the sewage with the electrodes, where the organic objectionable matters and bacteria are considered to be destroyed.

The value of these claims has been seriously questioned by many competent investigators.

6. Plants.—Plants on a working scale have been installed at Elmhurst, N. Y.,[1] Phillipsburg, N. J.,[2] and Allentown, Pa.[3] Tests on commercial size units were conducted at Easton, Pa.,[4] and Decatur, Ill.,[5] while smaller units were tested at other points.[6]

7. Varying Viewpoints.—Viewpoints have been strikingly at variance concerning this process. Fuller[7] has stated that the process was expensive for the work accomplished, with efficiency closely resembling that which could be produced by excess quantities of lime applied to sewages having high lime and magnesia content; the amount of organic matter oxidized by nascent oxygen was comparatively small and the apparent non-putrescibility of the well clarified effluent was not due to oxidation of organic matter so much as to the "pickling" action of caustic lime. He did not question the production of a well clarified effluent which would not putrefy for some time, the absence of nuisance around the plant, or the advantageous use of the sludge, with its high percentage of lime, on some kinds of land. The volume of sludge is relatively very large.

Proponent's Viewpoint.—In discussion of the foregoing summary, a proponent of the process, H. P. Bascom, claimed as follows:

A very significant feature about the operation of the direct-oxidation process is that it is mechanical in nature and depends for its success, not upon the delicate adjustment of conditions in an endeavor so far as possible to favor the caprices of bacterial life, but solely upon simple

[1] Eng. News-Record, 1914, Vol. 70, pp. 284, 292, 315, and 429.

[2] Eng. News-Record, 1919, Vol. 83, p. 584; and 1924, Vol. 92, p. 874.

[3] Eng. News-Record, 1922, Vol. 89, p. 659.

[4] Eng. News-Record, 1919, Vol. 83, p. 569.

[5] Eng. News-Record, 1915, Vol. 71, p. 775; and 1916, Vol. 74, pp. 455, 577, and 596.

[6] Toronto, Canada, Can. Engr., 1924, Vol. 46, p. 243.

[7] Proc. Am. Soc. Mun. Imp., 1922, 166.

mechanical contrivances whereby lime is fed into the sewage in sufficient quantities to render that sewage always slightly, but definitely, caustic, and thereafter to maintain an uninterrupted charge of electric current in the electrolyzers. Outside of these features the process is automatic.

The variation in flow of sewage through the electrolyzers up to the capacity of the unit has no effect upon the current required; in other words, any quantity of sewage up to the capacity of the unit requires the same amount of current as the rated flow.

State Health Department Rulings

8. Phillipsburg, N. J.—The New Jersey State Department of Health rated the Phillipsburg plant as of an experimental nature and permitted its approval as the equivalent of plain sedimentation, considered suitable for treating the local sewage before discharge into the Delaware River near the mouth of the Lehigh River. This will be noted in the resolution of that Board of Aug. 18, 1919, as follows:

Whereas, The State Department of Health has been unable to secure sufficient information regarding the efficiency of the direct-oxidation or "Landreth" method for the treatment of sewage to enable it definitely to determine at this time whether this process can be depended upon to treat sewage successfully at a reasonable cost, but from the information now available, however, the department is of the opinion that substantially the same results can be secured by the use of lime alone at a lesser cost, be it therefore

Resolved, that, if the inhabitants of the Town of Phillipsburg are desirous of installing a plant for the treatment of sewage by this method, this department will interpose no objection for the construction of such a plant as an experimental installation and its operation for a period of one year, provided:

1. That no sludge from said plant be discharged into the Delaware River or its tributaries at any time, and that a settling period of 6 hours, based upon the average sewage flow, shall be provided for the lime electric treated sewage.

9. Allentown, Pa.—The Pennsylvania State Department of Health permitted installation of the Allentown plant for observation purposes, with final approval conditioned upon tests to be made when sewage flow should approximate capacity of the first installation. At the close of 1925 official tests had not been made by the state, but Metcalf and Eddy studied the plant on behalf of the city. They found the quantity of energy required for treatment was 232 kilowatt hours per million gallons of sewage, of which 8 kilowatt hours were for the screen sweepers, 58 kilowatt

hours for the lime pulverizer and blower, 5 kilowatt hours for the lime feed apparatus, 46 kilowatt-hours for the lime feed pump, 36 kilowatt hours for the cleaning mechanism of the electrolyzers, and 79 kilowatt hours for the motor generators producing the direct current applied to the electrolyzer electrodes.

During the tests the sewage flow averaged slightly over one million gallons a day. Some 2037 pounds of lime (88 per cent CaO) were added per million gallons, and an average causticity of 62 parts per million was maintained in the electrolyzer effluent.

Sludge accumulated at the rate of 4550 pounds per million gallons on a dry basis during the test.

Operating costs for the year 1925, covering a total of 359 million gallons of sewage, amounted to $47.00 per million gallons, of which $24.80 was for labor, $7.80 for lime, $6.50 for supplies and repairs, and $7.90 for electricity. Metcalf and Eddy estimated these costs would be reduced to $33.10 for plant operation at full rated capacity. To this cost should be added fixed charges which they estimated would amount to $16.85 per million gallons, assuming interest at 5 per cent, and depreciation on sinking fund basis at 4 per cent.

Table 60 shows the characteristics of the sewage, the effluent of the electrolyzer and of the final settling basin, as found by Metcalf and Eddy.

TABLE 60.—ANALYSES OF SAMPLES OF SEWAGE AND EFFLUENTS, ALLENTOWN, PA. DIRECT OXIDATION PLANT

Constituent	Parts per million			Per cent reduction		
	Sewage	Electrolyzer effluent	Final effluent	2–3	3–4	2–4
1	2	3	4	5	6	7
Organic nitrogen	7.52	7.52	6.08	0	19.1	19.1
Albuminoid nitrogen	3.25	3.40	2.40	4.6*	29.4	26.2
Ammonia nitrogen	15.40	12.25	10.37	20.4	15.3	32.6
Nitrite nitrogen	0.29	0.49	0.54			
Nitrate nitrogen	0.25	0.93	1.12			
Oxygen consumed	155	168	94	8.4*	44.0	39.3
Suspended solids	139	611	50	340*	91.9	64.0
Oxygen demand (5 day)	188	219†	122†	16.5*	44.3	35.1
Relative stability, per cent	......	......	30†			
Bacteria per cubic centimeter						
Agar, 24 hours	751,042	111,760	2,361	85.1	97.9	99.7
B. Coli (presumptive test)	113,500	8,066	640	92.9	92.1	99.4

* Increase.
† Samples neutralized and seeded.

Attention should be called to the increase in suspended solids after the sewage passed through the electrolyzer, with corresponding sludge increase.

10. Toronto, Canada.—The Provincial Board of Health of Ontario tested the process at Toronto in 1923,[1] but developed nothing which would place the creditability of the method on a more secure basis than hitherto.

Oxidation Deficiency

12. Oxygen Produced.—Regarding the claims as to the production of oxygen by an electrolytic oxidizing device, it will be noted from Table 61 that, in four well known tests of the apparatus, in each of which the sewage treated was less than the nominal capacity of the cells, the theoretical oxygen produced was a trifle more than 3 parts per million assuming 100 per cent amperage efficiency. This represents only 1 to 2 per cent of the oxygen demand of typical American raw sewages, as indicated by studies by the U. S. Public Health Service[2] in which the

Table 61.—Electrolytic Features of the Direct Oxidation Process

	Toronto 1923–4	Easton 1918	Easton 1919	Decatur 1916
Nominal capacity of cell, million gallons per day	0.250	1.000	1.000	1.000
Average sewage treated, million gallons per day	0.147	0.460	0.464	0.859
Effective electrode area per bank, square inches (single polarity)	2760	5649	5649	5640
Number electrode banks in series	7	22	22	22
Average voltage on cell	17	57.5	62	40.5
Voltage drop per bank	2.43	2.61	2.82	1.84
Average amperes passed	35	33.8	34	66.8
Current density, milliamperes:				
Per square inch:	12.7	5.98	6.02	11.8
Amperes per square decimeter	0.197	0.093	0.093	0.180
Theoretical oxygen produced:				
Pounds 24 hours	3.86	11.73	11.91	23.1
Parts per million	3.1	3.3	3.1	3.2
Theoretical hydrogen produced:				
Pounds 24 hours	0.49	1.47	1.48	3.43
Parts per million	0.39	0.33	0.38	0.48

Toronto, 1923–4—Report of Dallyn-Johnson-Delaporte: Can. Engr., 1924, Vol. 46, p. 243.

Easton, 1918—Penn. Dept. Health tests; Eng. News-Record, 1919, Vol. 83, p. 569.

Easton, 1919—Franklin Institute tests: Jour. Franklin Inst., 1919, Vol. 188, p. 157; also Eng. News-Record, 1919, Vol. 83, p. 571.

Decatur, 1916—Report of Shields et al., 1916.

[1] Can. Engr., 1924, Vol. 46, p. 223.

[2] Public Health Bulletin No. 132, 1923.

average 5-day demand of raw sewage for 15 cities in various parts of the country was found to be 121 parts per million with an ultimate or total oxygen demand of 178 parts per million, corresponding to the 5-day figures.

Actually the dissolved oxygen is hard to find. Comparative tests running with and without current have practically no difference.

11. Winston-Salem, N. C.—Construction of a 15 million gallon plant was undertaken at Winston-Salem, N. C., in 1925, embodying apparatus not found in earlier installations. According to Landreth, the new features may be summarized as follows:

Fine screens of the Dorrco type for removal of large solids; improved apparatus for preparing milk of lime solution, for its application at rates proportional to the sewage flow and as necessary to maintain the desired degree of causticity; causticizing tanks to effect a uniform mixture of the lime solution and sewage; concrete electrolyzers with scrapers operating with a vertical, reciprocating instead of a rotary motion; and rotary vacuum filters for dewatering the sludge.

CHAPTER XXIX

CHLORINATION

SYNOPSIS

1. **Description.**—Chlorination is the addition of chlorine gas or of hypochlorites to sewage for the purpose mainly of destroying pathogenic bacteria. It has also been used to some extent with variable success for elimination of decomposition odors, control of flies at trickling filters and prevention of filter clogging.

2. **Process.**—Chlorine is usually applied as an aqueous solution by means of special apparatus designed to regulate the flow of chlorine gas obtainable in cylinders as liquid chlorine. When hypochlorite is used, solution tanks and orifice valves are required.

3. **Extent of Use.**—The application of chlorine to sewage is practiced in about 400 plants in this country.

4. **Efficiency.**—The effectiveness of chlorination is influenced by the size and nature of suspended organic particles in the liquor treated. Raw sewage ordinarily cannot be dependably disinfected. Settled or other partially purified effluent can be more effectively disinfected. To be practically effective, chlorine must be added in amounts sufficient to show a slight excess or "residual" after a contact period of 10 minutes. Thorough mixing, as well as a contact period 15 to 30 minutes after the addition of chlorine, is essential. When all of these factors are definitely controlled, removal of bacteria approaches 99 per cent of those originally present.

5. **Advantages.**—Chlorination has the advantage of being applied by inexpensive apparatus which can be handled by intelligent laborers. The equipment can be readily adjusted to cover a wide range of conditions. The cost for maintenance is small compared with the cost which would be involved in securing an equal degree of bacterial removal by other processes. Recent developments also indicate that as a result of chlorination the more readily putrescible matters in sewage are so changed in character that the oxygen demand is reduced to a degree varying with the quality of sewage and its dose.

6. Disadvantages.—It does not materially reduce organic matter. Therefore, chlorinated sewage will later decompose, to a greater extent than the effluents of processes by which the organic matters are more completely removed. In order to get satisfactory results, detention basins or long conduits must be built to provide the period of contact required for the chlorine to penetrate the sludge particles. The automatic devices do not regulate the feed in proportion to the strength of the sewage.

7. Present Status.—The use of chlorine for sewage disinfection is steadily increasing, where receiving bodies of water possess adequate powers of self-purification but do not give sufficient protection against bacterial pollution of neighboring waters. These instances are illustrated at seaboard cities, where chlorination is practiced to protect oyster-growing areas, and at cities on the Great Lakes, to safeguard bathing beaches and water works intakes.

PRINCIPLES OF CHLORINATION

While sewage treatment processes bring about considerable reductions in bacterial content, some of them, particularly intermittent sand filtration and the activated sludge process, may be and are operated to give high bacterial removal. In general, however, the remaining bacteria are still numerous, since the raw sewage may contain from 1 million to 25 million bacteria per cubic centimeter. From the bacterial standpoint, therefore, some processes do not entirely suffice where the effluent is to be discharged into streams immediately above water-works intakes or close to bathing beaches or shellfish layings.

For protection against possible water-borne infection in such cases, it is often prudent to supplement some treatment processes with chemical disinfection to reduce the bacterial content further.

Complete sterilization by chemical disinfection is not feasible because of the "resistant minority" of spore-forming bacteria, affected only by long contact with heavy concentrations of chemical. The removal of these resistant forms, however, is not requisite as a hygienic safeguard.

The need for and degree of chemical disinfection are necessarily dependent upon local factors. It is obviously futile to make sewage effluents markedly superior in quality to the water into which they discharge.

The most valuable disinfection methods for sewage involve the addition of chlorine solution, chlorine gas or compounds containing active chlorine, such as the hypochlorites. Chlorine gas has largely superseded hypochlorite of lime.

History

The practical application of hypochlorite of lime to sewage treatment dates back several decades. In early days its use was apparently for deodorizing treatment. Following the outbreak of cholera in 1892 at Hamburg, study was given to the use of hypochlorites as germicides. Substantially complete sterilization was striven for. In 1905, Rideal of London showed, however, that smaller quantities than hitherto considered practicable would destroy the vast majority of objectionable bacteria, although complete sterilization was not attained. This was promptly confirmed at Boston by members of the staff of Sedgwick and also by Clark. The practical development in America of this process of sewage treatment was largely due to the work carried out at various places under the direction of Phelps.[1] There have also been developed from time to time various processes for using hypochlorites prepared by electrolytic methods such as those of Webster, Woolf, Hermite and others.

THEORIES OF CHLORINE DISINFECTION

Chemists have long recognized that chlorine and hypochlorites in aqueous solution dissociate to form hypochlorous acid, which has marked powers of oxidizing unstable substances. The destructive effect of chlorine and hypochlorites on bacteria has been commonly accepted as due to nascent oxygen easily given up by the unstable hypochlorous acid. This view has been modified within recent years for several reasons. While chloramines lack oxidizing power and bleaching effect, they are destructive to bacteria and in certain instances when compared with small dosages of chlorine may produce a greater reduction after a sufficient contact period than chlorine itself. Sterilization by chlorine cannot be accomplished until the unstable organic matter

[1] For further details reference is made to Phelps: The Disinfection of Sewage and Sewage Filter Effluents, Water Supply Paper No. 229, United States Geological Survey, Washington, 1909.

is first satisfied with chlorine and enough more added to maintain an *adequate residual.* An additional reason why the disinfection is probably not an oxidation is that other inorganic chemicals having an oxidizing value equal or superior to chlorine do not have as great disinfecting powers. While the exact mechanism of destruction of the bacterial cell is not known, present evidence points to free chlorine and not nascent oxygen as being the cause. In other words, the chlorine apparently enters into combination with the cell proteins.

METHODS OF APPLICATION

Chlorine.—Pure anhydrous chlorine is available on the market as "liquid chlorine" and is commonly furnished in steel drums or cylinders holding 100 or 150 pounds net. For large users, chlorine is available in single-unit and in multi-unit tank cars of 15 tons net. Tank car shipments are utilized so far mostly by the paper trade and not for sanitation purposes, although the multi-unit car is employed in chlorination of the New York City and Philadelphia water supplies. Chlorine in the cylinders is under a pressure of 50 to 125 pounds at ordinary temperatures. When the pressure is relieved by opening the tank valve, the liquid chlorine volatilizes and chlorine gas is liberated.

During the past dozen years the use of chlorine has increased and a number of machines have been developed for feeding the gas. The first machine on the American market, put out by the Electro-Bleaching Gas Company, was followed by the Leavitt-Jackson, Wallace & Tiernan, Miller and Paradon devices. All have now disappeared from the market, with the exception of those made by Wallace & Tiernan, Inc., and by the Paradon Engineering Company.

In most control devices measurement of the chlorine is based on the loss in pressure of the gas in flowing through a fixed orifice, as indicated on a suitably calibrated manometer gage, reading usually in pounds per 24 hours. Regulation is secured either by varying the gas pressure on a fixed orifice or by varying the orifice under fixed pressure. Where the dosing rate is small there are available other types of apparatus which depend upon the intermittent syphonic displacement of a definite volume of the chlorine gas or the rate of bubbling through water. Although chlorinators are furnished with calibrations whereby the delivery may

be gaged, it is customary to provide platform scales for taking the loss in weight of the cylinders at intervals and thus obtaining an accurate check on the rate of feed.

Devices for automatically proportioning the chlorine to meet changes in sewage flow have not, as a rule, proved as satisfactory as hand regulation. Manual control of the feeding rate is therefore the usual practice. Semi-automatic devices, which cause the feed of chlorine to start and stop simultaneously with sewage pumps are, however, obtainable.

Chlorine delivered by the machines may be fed as a gas through porous diffuser plates submerged in the sewage. Solution type feeds, whereby the chlorine is absorbed by a stream of water and thus taken to the point of application, are preferable wherever a supply of water is available.

Hypochlorite.—Hypochlorite of lime, or bleaching powder, is available on the American market in light iron drums of 10, 25, 50, 100, 300 and 700 pounds capacity. This material contains, when fresh and of good quality, about 37 per cent available chlorine. When exposed to air, it rapidly absorbs moisture and loses chlorine, so that its value for disinfecting purposes quickly decreases.

In feeding bleaching powder, it is usually first worked up thoroughly with water in a dissolving box and then flushed into a solution tank, in which it is made up to the required volume and stirred thoroughly. The flow of solution is usually controlled by float box and orifice devices. On account of the tendency of the inert lime sludge to clog the orifice valve, it is customary to allow the mixed solution to settle before using.

The unpleasantness of handling bleaching powder, loss of chlorine in the sludge, its deterioration during storage, uncertainty as to strength and higher cost of treatment account for its waning use as compared with liquid chlorine. Approximately three times as much bleaching powder by weight is required to supply the equivalent in active chlorine as an anhydrous gas or as liquid chlorine.

Electrolytic Chlorine.—Most of the early work in chlorination of sewage was done with hypochlorite of soda produced by electrolytic decomposition of sea water or salt brine. Later these methods were generally supplanted by the use of bleaching powder as this material reached the market in larger quantities and on a cheaper production basis. At present, in spite of the

fact that cells for electrolytic production of chlorine gas have been developed to very high efficiency, there are no important installations at sewage treatment works for producing chlorine electrolytically, although there are a few such installations at waterworks plants. The cells used at these waterworks installations are generally of the low-voltage, diaphram type similar to those used in the manufacture of chlorine on an industrial scale.

Relative Merits of Chlorine Gas and Hypochlorites.—Rideal[1] found electrolytic hypochlorite to be a more effective germicide in sewage disinfection than its equivalent in chlorine gas. Phelps[2] concluded from his experiments that "gaseous chlorine is almost as good, but in each series the free chlorine is somewhat inferior to the hypochlorite." He found no difference in the efficiency of hypochlorite prepared with calcium, sodium or potassium base. He attributed the slight superiority of hypochlorite to its retarded activity, in comparison with free chlorine, in combining with organic material. This provides in the case of hypochlorite a greater relative final chlorine concentration, the importance of which in disinfection has been repeatedly demonstrated.

DOSAGE

In the case of raw sewage there are decided limitations to the effectiveness of chlorination, if the elimination of all disease-producing bacteria is desired. With large doses a great reduction of bacteria is possible, and the chlorine may be helpful in counteracting local odor nuisances. It is obvious, however, that the disinfectant will be slow to penetrate the larger particles or masses of suspended solids. The same applies in slightly less degree to raw sewage after passage through coarse rack screens. With fine mechanical screens the suspended solids not removed are more responsive to the action of chlorine through comminution.

Settled tank effluents are susceptible to satisfactory disinfection with chlorine, but when septic they require relatively high doses, due to the presence of hydrogen sulphide and other easily oxidized substances which have an avidity for chlorine. As treatment is carried further by subsequent processes such as contact, trickling and intermittent sand filters, disinfection with smaller doses of chlorine becomes more certain.

[1] Samuel Rideal: Sewage and the Bacterial Purification of Sewage, 1906.

[2] Earle B. Phelps: The Disinfection of Sewage and Sewage Effluents. W. S. Paper 229, U. S. G. S., 1909.

Controlling Factors.—The dose of chlorine required in practice varies widely, depending upon the strength, character and age of sewage, temperature, content of trade wastes, effectiveness of biological processes and local requirements as to purity of final effluent. Recent experience has shown that comparatively high doses are sometimes required to give desired results.

Importance of Mixing and Contact Period.—In disinfection of sewage effluents, it is important to have the chlorine intimately mixed with the sewage as well as to provide a substantial period of contact before the effluent is discharged into diluting water. The New Jersey Department of Health requires a one-half hour detention period in a baffled contact tank based on average sewage flow.

Bach, in connection with the studies cited beyond, calls attention to the importance of this retention period. He states that one-quarter hour should be regarded as a minimum, while a period longer than one-half hour is seldom necessary.

In some cases it may be advantageous to make use of the settling tanks of the treatment plant to provide the desired period of detention. In fact, there is evidence to show that at some plants the application of chlorine at the inlet end or half way across the tanks will materially reduce the odors and the dose, as compared with application at the outlet.

Control Tests.—Enough has been said to indicate the variable quantities of chlorine dosage required to sterilize sewage adequately. If hygienic factors are involved it is not safe to rely upon a stated dosage of chlorine, even though previous experience locally or elsewhere has indicated this amount to be satisfactory. The most satisfactory method of controlling chlorination of sewage, as in the chlorination of water supplies, is to base the dosage on a definite amount of *residual* chlorine found by actual test with orthotolidin or starch iodide, after a known period of contact. This residual cannot be definitely stated for any particular condition, but it should be determined at intervals by actual bacterial efficiency. In general, it may be stated that 0.5 to 1 part per million residual chlorine after 10 minutes contact will give dependable disinfection, although lesser amounts may frequently suffice.

While a high percentage of bacterial efficiency is an indication of good disinfection, it is much more important to know something of the number and kinds of bacteria which remain. In

water purification the percentage bacterial reduction, as an expression of the degree of purification, has largely given way to statements or standards showing the number and kind of bacteria remaining, particularly the density or prevalence of B. coli. Similarly, a knowledge of the number of bacteria and B. coli in the final effluent of sewage treatment works is of value in determining the suitability of the effluent for discharge into diluting water. Requirements in this respect must vary widely according to local conditions, such as the proximity of water intakes, bathing beaches, shellfish beds, etc.

CURRENT PRACTICE

New Jersey.—This is well illustrated by a recent rule of the Department of Health of New Jersey (1925) governing the design of sewage treatment works, which calls for a maximum chlorine feeding capacity, based on average sewage flow as follows:

Effluents from	Available chlorine	
	Parts per million *	Pounds per million gallons
Tank	Up to 20	167
Sprinkling filter followed by secondary sedimentation	Up to 18	150
Sand bed	Up to 12	100

* One part per million is the equivalent of 8.33 pounds per million gallons.

The above figures refer to maximum requirements and usually exceed the dose actually needed. It is understood that they are based on 30 minutes contact period and a reduction of B. coli to less than 100 per cubic centimeter (absent in 0.01 cubic centimeter). They represent the experience of the past 12 years with chlorine installations, which now total 46. Of these 13 use hypochlorite and the remainder liquid chlorine.

The doses of chlorine actually used by some of the New Jersey sewage works, as stated by F. W. Daniels at the 1926 Meeting of the N. J. Sewage Works Association, are as follows:

	Available chlorine	
	Parts per million	Pounds per million gallons
Atlantic City (coarse screens)	25	208
Ventnor (Imhoff tanks)	18	150
Ocean City (single-story tank)	14	117
Wildwood (Riensch-Wurl screens)	11 to 12	100
Millville (double sedimentation)	9 to 12	100
Morristown (sand filter)	3 to 7	59
Haddon Heights (sand filter)	1 to 2	17

New York.—Recent requirements (1924) of the Division of Sanitation of the New York State Department of Health call for maximum dosing capacities based on average flows, as follows:

Nature of sewage	Available chlorine	
	Parts per million	Pounds per million gallons
Raw	20	167
Settling tank effluent	15	125
Contact and sprinkling filter effluent	10	83
Sand filter effluent	5	42

Recent experimental work conducted by Tiedeman under the direction of Holmquist, Director of the Division of Sanitation, New York State Department of Health, on chlorination of Long Island sewage, showed that the tank effluent (with much suspended matter) at Huntington could be effectively treated with 6 to 15 per parts per million so as to reduce the 37° C. bacterial count below 800 per cubic centimeter and eliminate B. coli from 0.01 cubic centimeter. Disinfection was obtained only when residual chlorine was shown after a contact period of 10 minutes.

According to Tiedeman,[1] the Port Washington tank effluent required 26 parts per million chlorine to secure proper results in August at which time the effluent was markedly septic.

Further conclusions by Tiedeman (1926) resulting from studies of chlorination covering a period of ten months at Huntington, L. I., would seem to indicate a high efficiency of removal of total bacteria and B. coli from the settleable suspended matter discharged in the tank effluent. The reduction obtained with an average of 0.5 part per million of residual chlorine and a contact period of 15 minutes was 99 per cent or better, for effluents containing between 1 and 3 cubic centimeters of fresh settleable solids per liter. Examinations of the macerated solids indicated penetration by the chlorine and resulting efficiency of disinfection practically as great as was obtained in the liquid portion. The chlorine demand of this particular effluent smoothly decreased from a maximum of 15 parts per million in late summer to a minimum of 6 parts per million in mid-winter. An increase in chlorine demand was again observed to begin with the appearance of warm weather and continued to increase until mid summer.

Connecticut.—The Department of Health of Connecticut made tests in the winter of 1925–26 at the Imhoff tank plants at Stratford and Stamford, which discharge chlorinated effluents into Long Island Sound. The results, available through the courtesy of Scott, Director of the Bureau of Sanitary Engineering, show that a dose of 3 parts per million was effective at Stratford, but a dose of 6.6 parts per million was required at Stamford where the sewage is approximately twice the strength. At Stratford the bacteria at 37° C. were held by chlorination generally below 100 per cubic centimeter with B. coli absent in 0.01 cubic centimeter; while at Stamford the 37° C. counts were held below 500 per cubic centimeter with B. coli absent in 0.01 cubic centimeter. A dose of 7.3 parts per million at Stamford was found to give sterile results. Both sewages were fresh, with relative quantities of organic and suspended matters shown by the following analyses of the tank effluents.

[1] Journal A. W. W. A., 1925, Vol. 15, p. 391.

	Parts per million	
	Stratford	Stamford
Free ammonia	12.75	30.00
Albuminoid ammonia	3.28	2.50
Nitrites	0.16	0.30
Nitrates	1.00	0.05
Oxygen consumed	45.0	85.4
Total solids	303.0	1230.0
Volatile solids	106.0	290.0
Suspended solids	54.0	112.0

For the local conditions, taking into account tidal dilution, the above results were considered satisfactory. Summer conditions might modify the findings.

Cleveland, Ohio.—At the East sewage treatment works at Cleveland chlorination of raw sewage, following coarse screens, is used to afford protection to bathing beaches and also to the water supply intakes located some distance from the shore. This plant, with a capacity of some 6½ tons of liquid chlorine per day, is the largest installation in the country using chlorine for disinfection. The nominal dose is 10 parts per million, but this is not reached during peak flows.

Mount Kisco, N. Y.—Representing the other extreme, where the highest degree of bacterial purification is attempted, is the well known instance of Mount Kisco, N. Y., a village of about 4000 population on the watershed of New York City's Croton supply. Treatment comprises screens, settling, double-contact filters, secondary settling, sand filters and chlorination. A dose of 15 to 30 parts per million chlorine, applied to the effluent of the sand filter, results in a practically sterile effluent of better bacterial quality than the water supply which it enters. Operation is under careful laboratory supervision and the chlorine feed is adjusted to maintain a minimum residual of 0.35 part per million in the chlorinated effluent.

Providence, R. I.—At this chemical precipitation plant the sewage, averaging 32 million gallons daily, was treated in 1925 with lime bleach, equivalent to 2.35 parts per million of chlorine.

GERMAN EXPERIENCE

Emscher District.—Bach[1] has recently summed up the post-war experiences of the Emscher Corporation with liquid chlorine for chlorination of concentrated domestic sewage. He states the following doses as necessary to secure effective disinfection (99 per cent reduction of bacteria growing on gelatin) in concentrated fresh municipal sewage, which has not yet decomposed to any appreciable extent:

	Available chlorine	
	Parts per million	Pounds per million gallons
(*a*) For crude, unclarified sewage containing fecal matter	25 to 30	208 to 250
(*b*) For sewage clarified by ½ hour sedimentation, but which still contains fine settleable material	15 to 20	125 to 167
(*c*) For well clarified sewage	10 to 15	83 to 125

He further remarks, "If the sewage is very much decomposed, a part of the chlorine introduced is immediately used up in oxidizing the free hydrogen sulphide and alkali sulphides. Correspondingly large amounts of chlorine will then be required for disinfection proper."

Leipzig.—Since 1921, part of the sewage of Leipzig, and since 1923, all thereof, to the extent of 27 U. S. million gallons dry weather flow per day, from a sewered population of 700,000, has been treated with liquid chlorine. Part of the sewage is settled and some is not. The doses applied vary from 10 to 30 parts per million. Chlorination was adopted to supersede chemical precipitation of previous years. Funds were not available for oxidizing treatment of the sewage in spite of the receiving bodies of water having a low flow approximating only 300 cubic feet per second. The application of chlorine with a contact period of ½ to 1 hour, has been successful in providing bacterial reduction, lessening of odors, postponement of decomposition and elimination of growths of objectionable microscopic organisms formerly prolific in the adjacent streams.

[1] Technisches Gemeindeblatt, 1925, Vol. 28, p. 159.

PRICE OF LIQUID CHLORINE

The current published price (1926) per pound for liquid chlorine including freight on full cylinders and freight on empty returned cylinders is about as follows for the various territories listed below.

	Average Prices in Cents
(1) East of Mississippi and North of the Ohio and Potomac Rivers	
Tank car lots* (using single tank or multiple unit one ton type car of 15 tons net in either case)	4½
Car load lots (one hundred 150 lb. cylinders)	6
Less than car lots (150 lb. cylinders)	7½
(2) East of Mississippi and south of the Ohio and Potomac Rivers and also Texas	
Tank car lots (using single tank or multiple unit one ton type car of 15 tons net in each case)	5½
Car lots (one hundred 150 lb. cylinders)	7½
Less than car lots (150 lb. cylinders)	9½

* Single unit and multiple unit tank cars including the attached containers carry no freight charge on the car or containers in either direction.

COST OF CHLORINATION

The cost of chlorine delivered at the plant now ranges from 4½ to 10 cents per pound varying with the freight charges, size and nature of shipment and quantities contracted for. Each part per million of chlorine dosage therefore means a cost of between 38 and 83 cents per million gallons of sewage treated. It is thus seen that the costs of chlorination at Stratford, Conn., will be $2.50 per million gallons with chlorine assumed at 10 cents per pound and at Stamford, Conn., considered to be a fair size consumer, the cost will be $4.38 per million gallons with chlorine assumed at 8 cents per pound. With increasing size of plant and therefore greater annual consumption of chlorine, the cost per million gallons treated would be less.

When doses three to five times as great as those at Stamford are regularly used, the cost becomes sufficiently high to raise the issue of whether other methods of treatment may not be more advantageously employed. Such a question of relative advantages involves a consideration of how much of the objectionable constituents of the sewage taken as a whole may be eliminated for a given cost.

Beyond a certain point of chlorine demand, and therefore of necessary dosage, it will prove more economical to provide a

process which includes oxidation in some form, as well as a substantial removal of solids. After such oxidation, if it be essential, a relatively small dosage of chlorine will suffice to render the effluent from the oxidation process bacterially innocuous.

A balancing of the cost of chlorination against that of treatment by trickling filters, for instance, cannot be accurately made without specific data covering a particular set of conditions. These relate on the one hand to the strength of sewage, degree of septicity of tank effluent, and other items affecting the chlorine consuming power (or demand) of the sewage. On the other hand, it is important to consider the relative benefits which, in the case of trickling filters, include elimination of settleable solids and organic matter, so as to effect, non-putrescibility. We will not particularize on this proposition which involves details to an extent that is outside the scope of this volume.

RECENT RESEARCH

In addition to data and information supplied by the authors during the preparation of the foregoing portions of this chapter, communications and data have been received outlining results and tentative conclusions resulting from pending research by Enslow of The Chlorine Institute in association with technical advisers of plants at Dallas, Marlin, Austin, Fort Worth and Houston, Tex.; Schenectady, N. Y.; by the technical staffs of the State Health Departments of Connecticut, New York and Texas; and by the Harvard Engineering School.

It would be somewhat premature to discuss these data at length, but it is of interest to note the general conclusions drawn by these investigators.

(1) Thorough and prompt mixing of chlorine and sewage are of primary importance. A contact period in excess of 15 minutes is of secondary importance. A chlorine dosage sufficient to insure the presence of between 0.20 and 0.50 part per million of residual chlorine after a contact period of 10 minutes is essential for adequate disinfection. A positive test for residual chlorine should be obtained upon addition of 2 cubic centimeters of standard ortho-tolidin solution to 25 cubic centimeters of sewage sample and a contact of 5 minutes for color production.

(2) The chlorination of crude sewage or sewage screened through coarse screens is of questionable value save as an emergency measure for reduction of bacteria in the liquid portion; or

with the application of minor dosages for retarding septic action during the travel of sewage through sewers, pump wells, force mains, etc., to a point of disposal some distance away.

(3) The chlorine requirement to effect the presence of residual chlorine in a given sewage increases rapidly in proportion to the septicity of the sewage or to an active or *potential* source of hydrogen sulphide in the water of which the sewage is largely composed. Hydrogen sulphide comes largely from sulphate content; therefore the *potential* chlorine demand of sewage varies directly as the sulphate content. In the absence of sulphates the increase in chlorine demand resulting from an increase in the degree of septicity is not nearly so pronounced.

(4) To "healthy" or normal trickling filter beds, chlorine may be applied intermittently at the siphon chambers in concentrations sufficient to remove mats of organic growths from the top stone without injury to the functioning of the beds. Through this procedure the breeding of the filter fly, *Psychoda Alternata*, is materially reduced, if not almost completely eliminated. The pooling of the beds, clogging of nozzles, and odors resulting from organic growths may be simultaneously reduced.

(5) The application of relatively small quantities of chlorine may be applied whenever warranted for the reduction of odor nuisance around the plant to the primary settling tanks instead of to the siphon chambers. It appears that in many instances to effect chlorine economy in odor control the chlorine should be applied to the crude sewage at the inlet of the tanks, or to the tanks at the half-way point, and thereby prevent further septic action. The reason for this procedure is based on the fact that the sewage entering the tanks, being fresher than the effluent, requires less chlorine for a given effect, notwithstanding the fact that the solids in suspension absorb a fraction of the chlorine added.

(6) In addition to the value of chlorine as an effective agent to retard the putrefaction of the liquid portion and the very finely divided solids in the effluent, data are rapidly accumulating which indicate also an actual reduction of the putrefying qualities of the chlorinated sewage. Even prior to appreciable bacterial reduction it appears that the reaction of the chlorine on the matters subject to putrefaction is felt to an extent such that the oxygen demand decreases rapidly with increasing dosages of chlorine up to the point where residual chlorine is obtained.

After such point is reached a further reduction is less rapid in proportion to the further additions of chlorine. Contact periods in excess of 15 minutes do not appear necessary for maximum oxygen demand reduction. The extent of such reduction although appreciable cannot be considered as a competitor of trickling filters in situations where lack of sufficient dilution water requires more efficient reduction of oxygen demand than can be obtained through the process of chlorination alone.

CHAPTER XXX

BROAD IRRIGATION

SYNOPSIS

1. Description.—"Broad irrigation," "sewage farming" and "land treatment" signify the application of sewage intermittently to land in volumes such as not to interfere with the raising and harvesting of crops. When necessary the land is underdrained to facilitate the removal of the sewage after its percolation through the soil.

2. History.—This process dates back to the earliest days of the water carriage method for removing household wastes. About 1865 its status was enhanced by the recommendation of a British Royal Commission on Sewage Disposal that land treatment was the principal means of sewage disposal to relieve the increasing pollution of rivers. Prior to and for some years after the appearance of modern biological methods of sewage treatment, its adoption was advocated by European administrative authorities. This was true regardless of the availability of suitable areas of porous land. It was in consequence of this status in England by rulings of the Local Government Board, predecessor of the Ministry of Health, that the Royal Commission on Sewage Disposal was established in 1898.

3. Development.—In Europe for more than a generation prior to about 1895, this method was the principal one in vogue, although during the last 15 years of this period it encountered considerable competition from chemical precipitation, especially from the larger towns situated on fairly large streams. During this period large sewage farms were installed at Berlin, Magdeburg, Paris, Rheims, Birmingham, Nottingham, Leicester and scores of smaller cities.

4. American Status.—Beginning about 1875 sewage farming came into vogue, especially for institutional plants. It was used to a limited extent with intermittent sand filters in New England. Its adoption was chiefly in the arid regions of the Southwest where annual rainfall of about 12 inches occurs largely during a period of

about 3 months. In 1904 there were 14 sewage farms in the United States serving a population of about 200,000. In the report of the (1921) Los Angeles Sewage Disposal Commission (Fuller, Whipple and Mulholland), it was stated that in California 64 cities were making whole or partial use of sewage farms. In none of them were conditions fully satisfactory, although the quality of effluent was not a point at issue.

The first few broad irrigation projects in Texas were failures and were eventually abandoned. Amarillo irrigates feed crops with settled sewage. San Antonio delivers about 20 million gallons daily of raw sewage to a private company which irrigates some 4000 acres of land, and surplus sewage is stored in an artificial lake having an area of about 1000 acres. Abilene disposes of settled sewage by flooding alternate areas of land. Several plants located on wet weather streams are equipped with pumps to permit irrigating with sewage effluent during extremely dry weather, thereby alleviating conditions in river channels.

Ehlers points out that in recent years the experience with most American sewage farms has demonstrated that land irrigation with sewage might be successful if (*a*) suspended matter is first removed, (*b*) storage is provided during wet weather, (*c*) large areas of porous sandy soil are available and (*d*) settled sewage is applied in small doses and top soil permitted to dry, then turned over or plowed and permitted to rest between doses.

The histories of these applications of broad irrigation in the West are set forth in considerable detail in current text books on sewage disposal, particularly Fuller on "Sewage Disposal," Metcalf and Eddy on "American Sewerage Practice" and Kinnicutt, Winslow and Pratt on "Sewage Disposal."

5. Bypassing.—During the cropping season, particularly at harvesting, and again during rainy periods, experience in the United States shows that it is practically impossible to prevent at times the diversion of sewage to the nearest watercourse. In consequence in the arid areas polluted water reaches pools where it putrefies and causes complaint at locations several miles distant from the farms. On very large farms conditions may be alleviated by diversification of crops, by rotation of application to different subdivisions in turn and by storage basins. Obviously much help comes from proximity to large streams and from the use of preliminary basins for settling and storage as needed.

Advantage is taken of all these items and of efficient inspection at European sewage farms, as well as of porosity of soil at the better known successful sewage farms as at Berlin and Nottingham.

6. Kitchen Vegetables.—For over 30 years there has been strong prejudice against sewage farming in California on the basis that, unintentionally or otherwise, it would be used in growing vegetables which are eaten without cooking. Many federal, state and municipal regulations have beeen set up to meet this public health objection. Although scientific data in support of this prejudice are meager, the fact remains that the lay mind is suspicious of the whole procedure, even when a sewage farm is used to grow fodder for horses and cattle or groves of walnuts or other similar products.

7. Flies.—Campaigns to eliminate flies, privies and other insanitary conditions in the southern portions of the United States have made the public apprehensive about the transmission of disease germs by flies or other insects to locations considerably removed from farms on which fecal matters are exposed. Hence the situation prevails that, while sewage farming may produce ordinarily an excellent purification of sewage, the hygienic aspects, broadly considered, are disappointing under working conditions found in America.

8. Economic Aspects.—Theoretically there is some manurial value to sewage and in arid regions it also has a value as irrigating water. But for 365 days per year of performance to meet public health demands a truly balanced financial statement shows that in practically every American case broad irrigation is an expensive method. Practically it is a deficient one, hygienically, unless conditions are unusually favorable.

9. Present Status.—Modern biological methods have superseded broad irrigation in most English cities. In America it never reached a status of satisfactory performance. In Paris it is being supplemented by biological methods, particularly by the activated sludge process. At Berlin, when the suburbs were annexed in 1919, the trickling filter plants at Stansdorf (Wilmersdorf) and in other suburbs were discontinued. Areas of sewage farms near the city were available for sale for subdivision and other cheaper lands were within reach for sewage delivery. Hence the Berlin experience is one of the few that is not disturbing city authorities. The land at Berlin is fairly porous, effective

size 0.13 millimeter. The rainfall is low, say about 25 inches per year, and well distributed. At Magdeburg the farm has been practically abandoned for a fine screen plant, which is considered sufficient treatment before discharge into the river Elbe. Taken as a whole, land treatment can rarely, if ever, compete with other methods now available for sewage disposal.

PARIS

Size and Expense.—The Paris sewage farms had their origin in the late sixties, after extensive study preliminary thereto by French investigators. The sewage is now purified (1925) on approximately 12,000 acres, of which 1900 are in the Gennevilliers area, 3400 in that of Achéres, 5000 in the region of Mery-Pierrelaye and 2300 in the area of Carriéres-Triel. About 8100 acres of the total belong to individual farmers and 4500 acres to the city, which rents to individuals or to the state. During 1924 the city obtained from the area rented to private farmers approximately 133,000 francs, which, at the rate of exchange of 26 francs to the dollar, is approximately $5000. During the same year the total annual expense for the complete treatment of sewage amounted to 15,540,000 francs, or $600,000, at 26 francs to the dollar.

The City of Paris does not obtain a net income from the operation of the sewage farms. It costs the municipality on the average approximately 0.105 franc per cubic meter of sewage treated. Recently (1925) the municipality has attempted to impose on the farmers a tax of 40 francs to the acre, but the question has not yet been definitely decided.

Crops.—On these sewage farms fodder, cereals, potatoes, beet roots and market crops are usually grown. The total value of these crops amounts on the average to about 45,000,000 francs a year. The quantity of sewage applied to the fields for agricultural purification is restricted by the municipality to not more than 40,000 cubic meters per hectare per year, equal to 4,280,000 U. S. gallons per acre per year or 11,800 U. S. gallons per acre per day. Restrictions or regulations as to the use of crops have been set up which provide that vegetables, growing at shallow depths and which are to be eaten raw, are not to be irrigated with sewage water. Since the city controls the distribution of sewage, its authorities have formulated a contract with the

farmers. Whenever the above regulations are not fully complied with, the city can terminate the contract.

In 1925 Paris disposed of approximately 130,000,000 gallons of sewage per day by sewage farming. In winter it is said that operating difficulties require most of the sewage to be diverted into the Seine.

Advantages and Disadvantages.—The results obtained by this method appear to be wholly satisfactory to the municipal authorities, although they point out that the method is not particularly convenient, because of the necessity of making available extensive areas of land in close vicinity to the source of the sewage. The effort to have a sufficient quantity of such land available at all times must of necessity become more and more strenuous as the population of the environs of a large city increases. The extension of the present system of Paris will make it necessary to find land appropriate for this purpose at considerably greater distances from centers of contributing population. The conveyance of sewage to these areas will involve more and more expense.

Other Sewage Treatment.—In the mean time the Department of Sanitation of the City of Paris is operating fairly large scale sewage testing plants, of the artificial biological type, in order to supplement its irrigation farms and likewise to collect data looking toward the design and construction of artificial treatment plants for the future.

In 1908 a sewage testing station was established at Fond de Vaux where approximately 350,000 gallons of sewage are treated per day and in 1912 another plant at Carriéres-Triel where somewhat over 2½ million gallons of sewage per day are filtered. At the Mont Mésly sewage testing station of the Department of the Seine, the activated sludge process is the principal one under investigation.

RHEIMS

The total area of the fields used at Rheims is approximately 1800 acres, of which about 1100 acres are actually prepared for this purpose. Before the war Rheims disposed of 8 to 12 million gallons of sewage per day, corresponding to 25,000 cubic meters per hectare per year or 7500 U. S. gallons per acre per day.

The treatment is carried out in the same fashion as at Paris, excepting that the operation of the farms is in the hands of a farming company known as the Compagnie des Eaux Vannes.

EFFICIENCY OF FRENCH SEWAGE FARMS

In both Paris and Rheims the results obtained have been excellent from the standpoint of purification of sewage. Detailed analytical records for the year 1922 of the effluents of the various farms operated for or by the City of Paris may be consulted in the data prepared by Dienert.[1] The observations which he tabulates confirm amply the conclusion that the sewage may be completely purified by this method. These results might be profitably compared with those for the year 1901 as indicated in "Sewage Disposal" by Fuller. The filtered sewage leaving the underdrains is invariably clear and of excellent chemical, biological and bacteriological quality.

BERLIN

Similar successful performance has been characteristic of the sewage farms operated by the City of Berlin since 1876. In 1913 the municipality owned approximately 43,500 acres, the greater part of which was so prepared as to take the sewage from earth settling basins after the removal of coarse suspended matter. In 1926, the sewage from about 4 million people, or 150,000,000 U. S. gallons per day, was disposed of on 27,250 acres, according to the Director of Sewage Disposal of Berlin. The areas used are shown in Fig. 48.

So economical is this procedure considered in Berlin that, on expansion of the city in recent years to include the suburban area of Wilmersdorf, the existing sewage trickling filter installation at Stansdorf was abandoned and superseded by sewage farms.

In the case of Berlin, as in Paris, the more important crops are rye, wheat, barley, potatoes, beets and carrots. The effluent, likewise, is stated to be of good quality.

Cost.—It has been impossible to obtain detailed records of the financial status of the Berlin sewage farms since the war, because of the great fluctuations in money values in the last 10 years in that country. During 1925, however, the receipts from sewage farming were 1,146,000 marks, while the operating costs, exclusive of pumping, were 1,145,000 marks.

There are between 40 and 50 smaller cities in Germany which make use of broad irrigation for sewage disposal, with some degree

[1] Revue d'Hygiene, December, 1924, Vol. 46, No. 12, p. 1096; also Fuller, Sewage Disposal, McGraw Hill Book Company, Inc., 1912.

of success, in spite of the difficulties of applying sewage during cold weather and rainy periods, when the soil is already more than saturated.

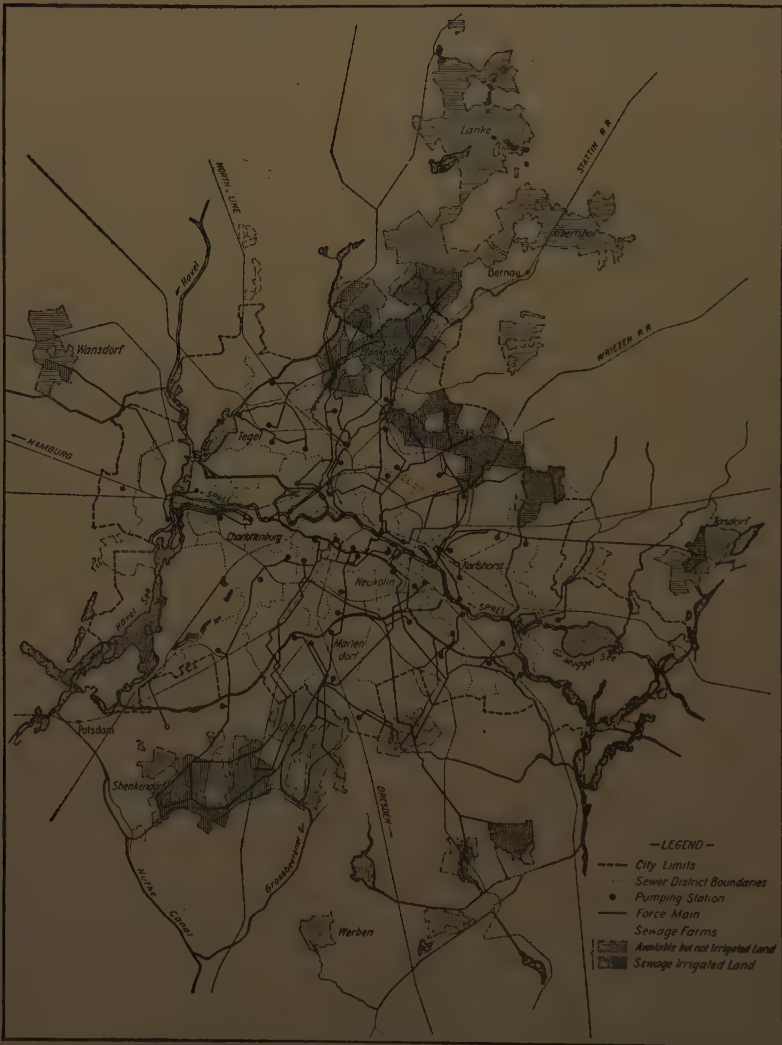


FIG. 48.—Map of Berlin Sewage Farms, January, 1925.

ENGLISH PRACTICE

In England sewage farms for the most part are being superseded by more intensive biological methods of treatment,

although the farms at Nottingham are still in service. Those at Reading have been superseded by a new activated sludge plant, although a portion of the sewage still reaches the sewage farms.

A considerable amount of the sewage is bypassed at various times at most of the English sewage farms, during extremely wet periods, when the soils are no longer capable of adequate filtration of the sewage applied to it.

The conclusions of the Royal Commission on Sewage Disposal in this connection are interesting. They appear in their Fifth Report substantially as follows:

(*a*) Effluents from land and effluents from artificially constructed filters are substantially alike. The quality of effluents varies with the adaptability of the soils.

(*b*) With preliminary treatment of sewage, and with the best land, a maximum rate of 36,000 U. S. gallons per acre, or 1000 persons per acre, appeared practicable. With heavy soils, such as clay, only one-tenth of this amount can be effectively handled.

(*c*) Large surplus irrigable area is desirable for emergency uses.

(*d*) To avoid decomposition on soil and damage to crops, solids should be removed, in general, previous to irrigation.

(*e*) Management of sewage farms is the most important item in successful sewage irrigation.

APPLICABILITY

Under favorable conditions sewage filtered through the material of a sewage farm represents the highest degree of purity that it is feasible to obtain. The process likewise makes use of the valuable materials in sewage. Unfortunately, when the sewage is not considered helpful for agricultural uses, there is too much tendency to divert it in its raw state to some neighboring stream. Although this difficulty may be eliminated by storage reservoirs and careful regulation and inspection, as actually has been done in some foreign countries, the control is usually subject to interruption.

Public Health.—The average layman is considerably prejudiced against the use of sewage on farms devoted to the production of foodstuffs. This prejudice is apparent not only in America, but in France and other countries. The scientific data in support of such prejudice are somewhat meager, but the interests of the public health demand that liquid sewage should not be applied to vegetables eaten raw. Many municipal, state

and federal governments have set up regulations for this purpose. In general, it is currently assumed in these restrictions that it is unwise to permit raw sewage in any form to come in contact with growing crops that may be consumed without cooking.

Some apprehension has developed in some areas as to the transmission of pathogenic organisms by flies or other insects from sewage farms. Although the danger from this source may be exaggerated, it is a problem which should be kept in mind. Unfortunately scientific prediction does not coincide with administrative practice, so that, on the whole, experience with broad irrigation for purification of sewage has been disappointing from the hygienic standpoint.

Cost.—From the financial aspect the procedure has obvious disadvantages, in that suitably located areas, isolated from centers of population, are usually difficult to obtain, particularly where necessary allowances for population growth must be made.

Restrictions.—Soil and climatic conditions play such an important part in the successful operation of sewage farms, that it is rare that both of these conditions are simultaneously favorable. Inasmuch as sewage is produced continuously, and the growing of crops, the saturation of soil, the occurrence of frost and the prevalence of rain are intermittent, experience has shown that all too frequently deficiencies in disposal arise through the conflict in the two groups of important factors.

Manurial Value.—The theoretical figures for the manurial value of sewage vary widely for different sewages and are contingent likewise upon market prices for nitrogen, potash and phosphates. Estimates have been made from time to time as to the probable values which sewage disposed of in this fashion might yield. The discrepancies between theory and practice, however, are usually wide and most of the sums ordinarily expected in revenue have rarely materialized.

WANING STATUS

In America broad irrigation has practically no standing as an independent method of purifying sewage in the humid regions of the eastern and middle sections. Its use is practically restricted to certain western arid regions and even there instances of sewage farming carried out in a sanitary way are few.

In a few European cities sewage farms have had more success. In no case, however, have they been financially profitable. Their

success as a means of sewage disposal is due partly to more favorable soil and rainfall conditions, but largely to the development of more careful, effective and continuous management.

In England broad irrigation is gradually giving way to more modern methods of sewage treatment. Lack of porosity of soil, long periods of wet weather and expanding areas of population have caused the method to disappear in favor of artificially constructed units.

The process requires large areas in order to reconcile the exigencies of agriculture with those of purification. It may sometimes create objectionable odors and it causes the production of flies. Its requirements of permeable soil and of crops whose first requisite is large amounts of water are not always to be realized. In addition, there are certain hygienic disadvantages attached to the process, such as the dissemination of disease through vegetables eaten raw or through pollution of underground water. In summary, therefore, it is fair to state that broad irrigation or sewage farming is likely to be largely superseded by more modern methods of sewage treatment in most cases.

CHAPTER XXXI

FISH PONDS

SYNOPSIS

1. Description.—Sewage, first freed of settleable solids, is diluted with two to four times its volume of fairly pure water and allowed to flow through shallow ponds, which are simple excavations without masonry walls or bottoms. These ponds are stocked with fish which feed upon various forms of aquatic life that grow in the diluted sewage. One acre of pond surface is provided for 800 to 1200 persons connected with the sewer system. It is essential to control operations by careful inspection in order to maintain suitable oxygen and biological balances (see Chapters VI and XI). Fish life requires not only suitable food, but ample dissolved oxygen. The absence of hydrogen sulphide and other products of anaerobic decomposition is essential, for these act as poison for the fish just as do certain acids and other industrial wastes.

2. History.—Fish ponds were first built in 1887 by the City of Berlin, chiefly for testing the quality of effluent from the sewage farms. At perhaps half a dozen other places similar use was made of fish in connection with other purification methods, more or less complete. As a self-contained purification process, fish ponds were proposed by Oesten in 1899. They were investigated and recommended for adoption by Hofer and Graf of Munich. Shortly before the war fish ponds were put in service at Strassburg in Alsace. Their status was enhanced in 1925 by the recommendation for their adoption as a part of the new disposal project for Munich, with a present population of 460,000.

3. Dissolved Oxygen.—As earlier explained some dissolved oxygen is needed for fish development. It varies with the species, with a minimum perhaps of 2.5 parts per million. This provision affects the needed degree of dilution with pure water and should take into account all the factors explained in Chapters X and XI in respect to reaeration and production of oxygen by green algae. It involves also the consumption of oxygen by bacteria and other types of plant life, as pond lilies.

4. Absence of Poisons.—Fish are very sensitive to poisons or products which stick to their gills and interfere with normal breathing. Decomposing deposits on the bottom of the ponds are highly objectionable and their occurrence should be prevented or the deposits should be removed as required.

5. Discontinuance in Winter.—Ice and other features attending freezing temperature require in northern climates the emptying and cleaning of fish ponds in the autumn. During the winter the settled sewage is disposed of either by discharge into a stream, with adequate flow for dilution, or by land treatment between cropping seasons, or by some combination of suitable inexpensive methods. In the spring the ponds are filled and stocked with fish.

6. Economic Aspects.—Data from a sufficiently large plant in actual operation are not at hand to permit discussion. Both the German and the French authorities at Strassburg think sufficiently well of the process to advise its continuance and expansion. A particularly important economic point for localities where there is little diluting water is the feasibility of returning pond effluent in a well aerated condition to the influent, thus using water over and over again for mixing with the settled sewage. The question involves the effect of concentration of various products of biological activities.

7. Present Status.—The plants in Europe have operated without any objections to sight or smell, according to available experiences. In combination with some other natural or artificial form of sewage treatment the method offers the advantage of recovery of food. It may be profitably and practicably operated when sufficient diluting water of proper character is available. A high degree of purity of effluent is attainable where cost of land is not too high and where topography makes the construction of such ponds reasonably economical. Its use for some years at Strassburg for a considerable quantity of sewage and its favorable acceptance there for the future, its adoption in 1925 by Munich as an integral part of its disposal program and its proposed use at Heidelberg all point to the conclusion that it is considered, at least in Continental Europe, as a practical purification method.

PRINCIPLES

The conversion of sewage in fish ponds was given its first emphasis by B. Hofer of Munich, who pointed out that sewage

contains a considerable proportion of organic material which might be made available under favorable conditions for the development of fish life. In the cycle of food consumption and digestion in the universe at large, the two end products of biological reactions are sewage and fish meat. The waste products of man are carried from communities through sewers to a point of disposal. All efforts at natural and artificial methods of treatment result usually in the conversion of these wastes, through the help of bacteria, protozoa, plant life and higher animals, into new food products.

Hofer pointed out that where sewage effluents were emptied into streams and such a biological cycle was carried forward, the procedure is an uncontrolled one. As such it does not result in a maximum economic usage of the organic materials available in sewage. He suggested, therefore, the use of artificial fish ponds in which the application and regulation of sewage flow could be intelligently carried out and where a conversion of lifeless organic substances into living organisms might be artificially and efficiently accomplished. The advocates of fish ponds further maintain that the problem of sewage disposal is not only that of purification and the rendering of sewage unobjectionable, but is also one of recovering valuable food products. In other words, the organic materials of economic worth which each day are carried off from the city are returned in part thereto in the fish market. In this respect, only sewage farms have been comparable therewith, although there are now prospects of recovery from sludge of fertilizer and of gas. In all other processes, they point out, sewage treatment destroys, rather than recovers, values.

There are three primary ways in which the organic content of sewages is made available to living organisms, namely: (*a*) through splitting of the organic material by bacteria and the use of the decomposition products by the bacteria themselves; (*b*) through splitting by bacteria and the use of the decomposition products, as well as the bacteria, by algae and higher plant forms; and (*c*) the consumption of living or decomposed or undecomposed organic substances and organisms by every gradation of infusoria, worms, snails, insect larvae and fish and subsequent resorption through the digestive secretions in these animals. In this combination of biochemical purification lies the purpose of fish pond treatment.

The process depends for its successful performance upon the retention in fish ponds of a sewage substantially free from excessive suspended matter, toxic materials and anaerobic fermentations, together with proper temperatures and dissolved oxygen contents. These requirements must be carefully regulated in order that fish life may be adequately sustained and nurtured to the maximum growth compatible with the organic conditions of the sewage to be treated.

HISTORY

The first fish ponds fed by sewage were built by the City of Berlin in 1887 in connection with the sewage farms of that city at Malchow. In this instance, however, they were used as an indicator of the degree of purification accomplished by the farms and not as an integral part of the sewage treatment process. The ponds were fed from about 500 acres of sewage farms. Each pond was of from 700 to 1000 square yards area. Various species of fish were placed in them. When the ponds were emptied in the autumn of the same year, 1295 healthy and well grown specimens were found therein.

Although the suggestion was made by Oesten in 1899 of adapting fish ponds to the treatment of sewage, through stocking such ponds with various forms of animal and plant life, the credit for giving practical form to the undertaking is actually due to Hofer, Professor of Zoology at Munich, so that, in continental countries, this particular method of sewage purification is spoken of as the "Hofer" fish pond method. In conjunction with Graf, of the Institute of Biological Research of Munich, a series of such installations was constructed by Hofer. The largest of these which are still in operation are the fish ponds in Strassburg in Alsace-Lorraine. These will be described at greater length below.

Graf also was responsible for the installation of fish ponds for sewage treatment in Amberg, Grafenwohr, Kitzingen and Zerzabelshof. A similar installation of large size was also in operation in Spandau some years ago.

PROCESS

Preliminary Treatment.—The process usually consists in preparing the sewage by some preliminary treatment for holding

in the fish ponds. The experiments at Strassburg indicated that the ponds could not be successfully operated for any period of time if the sewage was not settled at least before application thereto. Experiments definitely showed that without pre-settling the fish ponds would fail in their operations through the accumulation of sludge. The necessarily frequent removal of the accumulations of such sludge from the ponds increased the cost of operation so greatly that the procedure became uneconomical. Screening of the sewage was not particularly successful in preventing sludge accumulation. Operating experience shows that it is desirable to remove from 50 to 60 per cent of the suspended particles of the sewage before allowing it to enter the ponds. In many instances this is accomplished by settling the sewage in tanks before application to the ponds. The period of detention of the sewage in settling basins should not be needlessly prolonged, so that the resultant effluent will reach the pond in an aerobic state, in order to avoid the deleterious effect of deoxygenated or septic sewage. Sludge should be removed from settling basins every 2 or 3 days or at least every week in order that clarification is not interfered with and that anaerobic conditions in the effluent are not promoted.

In other instances, fish ponds are fed by the effluent of more elaborate treatment plants, such as in Brunn, where the sewage passes through a settling tank and then through sand filters.

Dilution of Sewage.—For adequate operation of ponds the clarified sewage should be diluted with two to four times its volume of clear and fairly pure water, before it is available for use in the ponds. If the effluent is a highly purified one, such dilution, of course, is not essential. Omission of dilution may sometimes be feasible when the effluents of trickling filters enter the pond. The amount and the frequency of the dilution depend upon the character of the sewage effluent. The warmer the diluting water the more favorable the results, provided the temperature does not become excessively high. In most plants operating in this way, the diluting water is added in the day time, but not at night, since at that time the concentration of the sewage itself is lowered. Where surface water is not available for such dilution, local ground water supplies have been developed. In such instances, however, it is important to determine whether the hydrogen sulphide content of the ground water is not excessive and whether the temperatures of the water are not too

low. The diluting water may be aerated in order that the oxygen saturation of the mixed water is kept at a maximum.

Mineral Content.—Due consideration should be given to the iron content of waters which are used for diluting purposes, since excessive contents of iron may result in precipitation of ferric hydroxide in the gills of the fish with detrimental effect upon their breathing. Ferrous and ferric sulphate, according to the researches of Konig and Hazelhoff, become toxic to tench and gold fish at a content of about 15 to 50 parts per million. According to Weigelt, the harmful concentration of ferrous sulphate for rainbow trout is reached at about 100 parts per million. Manganese up to 5 parts per million was found to be harmless by the same investigator.

Control of Plant Growth.—For proper operation of the ponds, they should be stocked with ducks, which control the growth of duckweed on the pond. These weeds interfere with the adequate reaeration or oxygen supply of the pond. About 400 ducks per hectare or 160 per acre are usually provided.

TYPICAL PLANTS

Strassburg.—The best known of the fish ponds developed in Germany and France are those of Strassburg. Experiments were carried out upon 12 acres divided into ponds ranging from 0.8 to 1.5 acres in size. Each of these is from 130 to 170 feet wide and 325 to 500 feet long. They are 1 foot deep on the perimeter and 2.5 feet in the center. To provide for hibernation of the fish, three deeper ponds have been constructed.

The water is diluted with three times its own volume with the water of a branch of the Rhine. Before the ponds were filled, they were seeded with aquatic plants and animals necessary for food supply for the fish. Special hibernating basins for these plants and animals were also provided. The ponds were stocked with carp. The Strassburg experiences indicate considerable trouble with water lilies depriving the ponds of the necessary oxygen. In addition, the process demands continuous attention in order to avoid excessive development of aquatic plant life. The ponds must be examined every day, for they do not all function in the same manner. Sewage should sometimes be decanted, since experiments have shown that without this precaution fermentation and objectionable deposits may be produced in the basins.

The Strassburg studies indicate that 1 hectare of pond area is sufficient for the purification of an effluent from a city of 2000 inhabitants, or approximately 1 acre to 800 persons. In order to purify all of its sewage, by this procedure, the city would require about 200 acres of pond area. It has this amount of land already available.

In the winter and autumn they find it necessary to empty the ponds for drying and cleaning. During this period sewage irrigation on land or some other form of treatment, according to local requirements, must be provided.

The results obtained by purification in fish ponds at Strassburg have been very satisfactory; 88 per cent of the organic material and 80 per cent of the nitrogen are removed from the sewage. There are no odors and no flies. The effluents are clear and contain about 10,000 bacteria per cubic centimeter. There has been no appreciable deposit of putrescible matter in the bottom of the ponds.

Dienert stated in a recent discussion of the Strassburg experiences (Revue d'Hygiene, December, 1924) that sewage from the standpoint of hygienic performance may be adequately purified by this process. Similar conclusions have been stated by Levy and Feser who have made analyses of the effluents of the Strassburg fish ponds. Their detailed results are set forth by Reinhard Demoll in the text noted in the bibliogaphy attached to this chapter.

Heidelberg.—City Engineer Schwaab proposes, when the necessity arises, to use fish ponds for final treatment of the effluent from the fine screens now in operation.

Munich.—Keppner, technical director of sewage operations at Munich, is constructing (1926) fish ponds for the treatment of the clarified sewage. These ponds will be about 7 kilometers in length covering a total area of about 600 acres. At first the ponds will be supplied with a mixture of 3.6 cubic meters per second of sewage and 10 cubic meters per second of fresh water from a nearby power canal. When another plant is completed these figures will be raised to 7.2 cubic meters per second of sewage to 36 cubic meters per second of fresh water. He calculates that approximately 800 acres of pond area should provide for a population of 1,000,000.

Keppner estimates that the sewage fish pond will yield annually 1000 pounds of fish meat for each hectare, or from 233 hectares

about 116½ tons, equal to about 440 pounds per acre. He also expects to raise ducks on the ponds and is anticipating a yield of about 550 pounds of duck meat per hectare or, on a total of 233 hectares, approximately 64 tons of duck meat.

Other German Practice.—In 1921, in the fish ponds at Grafenwohr, covering an area of 5½ hectares, about 8500 marks were earned. In general about 1100 pounds of fish per hectare were grown.

At Strassburg from 450 to 500 pounds of fish meat were produced per acre. At Konigsburg and Brunn, about 530 pounds of fish per acre resulted.

The fish pond method has been used at Konigsburg, among other things, for the purification of the waste waters from a sulphite pulp plant. The wastes are diluted, in the ratio of 1 to 10, with brook water. The minimum safe dilution was found to be 1 to 5. Satisfactory purification was obtained and considerable carp were raised.

OPERATION DETAILS

An important feature of the operation of the ponds has been regularity or equilibrium in the bacterial and bacteria-consuming environments. A practical indicator of the biological character of these environments is their content of hydrogen sulphide. For this reason some of the fish pond installations provide for the discharge of the sewage, before entering the main ponds, into a small preliminary pond, which is stocked with test fish, preferably perch, highly sensitive to hydrogen sulphide. Special emphasis is likewise placed upon the detection of the development of objectionable forms of plant life. Certain plants are toxic and others are objectionable from the standpoint of destruction of light and food.

Stocking of the ponds is usually started in the spring months. In October, at the end of the fattening season, the ponds are emptied. Carp and tench are the usual types of fish used. When the mixed sewage and diluting water permit, rainbow trout are also used.

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CHAPTER XXXII

SUBSURFACE IRRIGATION

1. Description.—A subsurface irrigation system consists essentially of a system of tile pipes laid in shallow trenches throughout an area of natural or artificially prepared porous material. A settling or septic tank and a dosing siphon or other means of controlling the amount and time of discharge of sewage to the piping are necessary parts of the system.

2. Process.—The process of purification is somewhat similar to that of oxidation by means of contact beds or sand filters. Intermittent application of the sewage is essential in order that resting periods may be provided for the soil to recover its oxidizing capacity. Thorough preliminary removal of solids and of grease is necessary in order to prevent clogging of the soil around tiles.

3. Extent of Use.—Subsurface irrigation originated in England, but was introduced in this country by Waring, Philbrick and other leading sanitary engineers, who advocated its use following the invention of the automatic siphon. It has been, and still is, quite extensively used for disposal of sewage from isolated residences, schools, institutions, and industries. It is particularly serviceable for summer hotels and country clubs, where disposal is required during only a portion of the year. It is very little used, however, in connection with municipal works, although there are a few instances of its use for treatment of the effluent of septic tanks in towns of a few hundred or more inhabitants.

4. Capacity.—The length of tile required per capita or per gallon of sewage varies with the character of the soil. In general, with sandy soil or light porous loam, which are most favorable for this method, a length of 20 to 40 linear feet per capita is required, wth perhaps 35 feet as an average. For heavier soils, 75 to 100 feiet may be required, but in clay and hardpan the method is not applicable.

5. Efficiency.—Under suitable working conditions this method of treatment is highly efficient, and produces a thoroughly clarified and nitrified effluent.

6. Advantages and Disadvantages.—Subsurface irrigation systems are less troublesome and expensive to operate than other methods of disposal. The sewage is not exposed to view, and thus unsightliness and odors and the nuisance and danger from flies and other insects are avoided. This is particularly advantageous in permitting the disposal of sewage to take place near the buildings from which the sewage comes. But in order that these advantages may be enjoyed, suitable areas of reasonably porous soil must be utilized; the preliminary treatment of the sewage should be such as to reduce to a minimum the suspended matters contained in the sewage; any appreciable amounts of grease and soap, which would clog the soil, should be removed by suitable grease traps; the dosage should be of the right quantity and applied at suitable intervals; and, in order that the tiles may not become clogged by the surrounding soil, great care should be used in protecting the joints and avoiding settlement or displacement of the tiles. Precautions should be taken in the location of subsurface irrigation systems that no pollution of wells or other underground water supply is possible. This is particularly necessary in cases where the soil is of an open, gravelly nature.

7. Present Status.—For disposal of the sewage of small aggregations of population, this process has a very high standing, and its use is advised and approved by state health authorities wherever local conditions are at all favorable.

8. Lack of Definite Basis for Design.—Although much has been written about this method of disposal, experimental data and results of continuous observation of practical operation are generally lacking. Perhaps the most useful contribution to this topic is that published in the Journal of the American Public Health Association in 1921, which discusses the theoretical basis for design. It is in any event necessary to use judgment as to the loading which may be applied to any particular soil; but in addition to this, actual practice varies widely regarding many important features.

9. Details of Systems.—For preliminary sedimentation, a single-story septic tank is most frequently used. This is ordinarily followed by a dosing tank, containing a dosing siphon or

hand-operated device for discharging the sewage intermittently, in such volume as not to flood the pipe system. The field is preferably divided into two or more separate areas, to permit certain portions to rest after having been in service for some time. The tiles, usually 3 or 4 inches in diameter, are laid in approximately parallel rows, on gradients of 2 to 6 inches per 100 feet, and so as to follow in general the contour of the ground. They are usually about 12 inches deep, but sometimes deeper. The rows are usually spaced from 3 to 6 feet apart. Joints are left open for a space of about ¼ inch, and covered with a half collar of pipe of larger diameter, or with tar paper or burlap. The joints are frequently surrounded with gravel or cinders, especially in heavy soils or soils of medium grade. Underdrains are sometimes used to drain the effluent away more readily, and also where the ground water level would otherwise be too high.

If a dosing tank or hand operated device for discharging sewage in comparatively large quantities is not included, the sewage will not enter the piping in sufficient volume to reach all portions of the system, but will be absorbed by the soil near the inlet end. The portions of the system which are thus constantly overloaded will gradually become clogged, forcing the sewage to flow a little farther along the tiling and progressively clogging the whole absorption system.

10. Trenches Filled with Stone.—In some localities, where the soil is so dense as to afford little likelihood of being otherwise successfully used, trenches 3½ or 4 feet deep are excavated, filled with broken stone or cinders to within about a foot of the surface, and then covered with loam. Sewage is delivered intermittently at the top by means of tile distributors, and small underdrains are generally provided for removing the effluent.

11. Artificial Fields.—In some cases artificial fields are made of sand beds, containing an upper set of tiles for distribution and a lower set for drainage. The surface of the sand bed may be seeded or covered with turf. Such fields are built for golf clubs where treatment must be provided in exposed locations.

CHAPTER XXXIII

INTERMITTENT SAND FILTERS

1. Description.—This method consists in applying comparatively small volumes of sewage to areas of porous sand, allowing the sewage to drain from the pores of the material, thus filling the pores with air, and in repeating the doses of sewage some hours or days later. In other words, the sewage is allowed to remain in the pores of the filter for a sufficient time, in the presence of air and the necessary bacteria, including nitrifying organisms which become established on the surface of the sand grains, to become purified.

2. Origin.—The process of purifying sewage by means of intermittent sand filters is of English origin, although German investigators, beginning about 1865, also contributed much to its scientific foundation. Following the experimental work of Frankland for the Rivers Pollution Commission of Great Britain, the first application of this process was made in 1871 by Bailey-Denton at Merthyr-Tydvil, Wales. The process did not thrive in Europe, partly because of limitations in available areas of porous sand and partly because the cultivation of lands for crops interfered with sewage disposal. Following the advent of the germ theory of disease and particularly of more refined methods of bacteriology, the well known investigations were begun at Lawrence, in 1887, by the Massachusetts State Board of Health. Due to these tests and to the fact that areas of porous sand were available in Massachusetts and other New England states, there resulted a well defined custom in that vicinity of installing intermittent sand filters.

3. Oxygen Requirements.—Perhaps one of the most important conclusions reached at the Lawrence Experiment Station, as to the relation of the oxygen supply to nitrification processes in intermittent filters, is that stated herewith from the special report of the Board (1890, part 1, p. 730):

"In these experiments it was found that nitrification was as complete when the oxygen content of the air in the filter was as

low as 1 to 3 per cent as when a larger quantity was present, provided the constant circulation of air was maintained through the material."

Intermittency of application is essential, for continuous application of sewage would cause the sand pores to remain filled with liquid, and thus prevent the entrance of sufficient air to bring about oxidation. Under such circumstances oxidation and nitrification would disappear, putrefaction within the filter would soon result, and the process become no more than a simple straining operation of no merit. It is obvious also that the sand surface should be kept moderately free from clogging in order to bring about the ventilation necessary to maintain oxidation.

4. Extent of Use.—In 1904 there were in this country, largely in New England and principally in Massachusetts, 41 intermittent sand filter plants, serving a population of about 250,000. During the past 20 years practically no large installations have been made. Except in New England and a few other localities having natural deposits of sandy soil, the process has not been found adaptable. Sand filtration was thoroughly investigated at Baltimore and Columbus prior to the adoption of trickling filters at those places, but was rejected on account of lack of available sand of suitable size and porosity and because of the cost of transporting suitable sand from a distance.

Nevertheless, for many small residential towns and for institutions, sand beds have been and will probably continue to be used with much success. They are considered to be more reliably efficient than other methods of treatment, especially for small plants where skilled supervision is not available.

5. Rates.—It is quite common to find average rates of treatment per acre of 75,000 to 100,000 gallons daily, in cases where the sewage receives little or no preliminary treatment. Owing, however, to the varying strength of sewage, it is better to express the permissible loading in terms of the number of persons connected with the sewers. Experience has shown that an average loading over a term of years may be taken as 600 to 700 persons per acre. For limited periods, particularly in warm weather, much higher rates are fairly satisfactory. The Local Government Board of England, where winter weather is much milder than in the United States, prescribed about 1890 that at least 1 acre of intermittent sand filters should be provided per 1000 connected population. For settled sewage, rates of filtration

up to 150,000 gallons per acre daily are considered permissible; and this was the basis for estimates in 1906 at Baltimore, with sewage assumed to average 100 gallons per capita daily.

6. **Efficiency.**—This process is the most complete method available for operation on a reasonably large scale. It produces a clear effluent which will not decompose upon standing. Removal of bacteria will approximate 98 to 99 per cent, and of organic matter about 90 to 98 per cent.

7. **Construction Features.**—Filter material should be reasonably uniform in size. Strata of clay or fine sand are objectionable because they result in clogging and consequent exclusion of air. The upper 12 inches of filter material effect most of the purification; but greater depths, up to 4 feet, are usual, largely to prevent short-circuiting of the sewage to the underdrains. Less depths than 4 feet are suitable where tile underdrains, having open joints surrounded with graded gravel, are spaced 10 to 15 feet apart. In deep beds, underdrains should be spaced not over 30 feet apart.

8. **Operating Features.**—In order to prevent surface clogging by retained suspended matters, frequent cleaning and occasional harrowing and scraping are necessary, with replacement of the top portion of the sand at intervals. During severe winter weather freezing of the surface is ordinarily avoided by ridging and furrowing the surface of the beds, but winter operation always requires good management to get efficient results.

9. **Final Treatment.**—Sand filters have been installed in comparatively recent years in New York, New Jersey, Maryland and other eastern states, to provide final treatment after the sewage has been passed through coarse-grained filters. This custom has been due to the reliability of sand filters and also to the high grade of effluent which they produce, enabling sand filters to take the place of chlorination for final treatment, although sometimes both are used. When sand filters are used in this manner, rates several times as high as when they receive raw sewage or tank effluent are practicable.

Sand filters are used at Chatham, N. J., following Imhoff tanks, contact filters and secondary Imhoff tanks. The connected population is now about 5800, and the sewage flow averages about 500,000 gallons daily, with a maximum of about 750,000 gallons. These sand filters are in four units and have a total area of about 1 acre and a depth of 2 feet to 2 feet 3 inches.

The loading is therefore 5800 persons per acre or an average of about 500,000 gallons daily of settled contact filter effluent.

At Morristown, N. J., having a total population of about 13,000, the disposal plant consists of single-story settling tanks and single contact filters, followed by sand filters. There were four sand filters, each having an area of about 0.38 acre, and a depth of 3½ feet. The average sewage flow is about 1.1 million gallons daily. Each contact bed is directly connected to a sand filter, so that the contact filter acts as a dosing tank for the sand filter. The cycle of operation was thus the same for the contact filters and sand filters. The average loading per acre per day was somewhat over 700,000 gallons of contact filter effluent during the war, after which the area of sand beds was materially increased.

In 1924–5, a disposal plant was built at Boonton, N. J., for treating the sewage from Dover and other municipalities located in the valley of the Rockaway River. This plant is described in Public Works, July, 1925. This project, which was constructed in order to prevent pollution of Jersey City's water supply by municipalities located above the Boonton reservoir, was opposed in court by the water company using the river below as a source of water supply. The activated sludge process, at first proposed, was opposed by the water company, on the ground that this process was still in an experimental stage, but a plant consisting of settling tanks, separate sludge digestion tanks and single contact beds, followed by sand filters for insuring the purity of the effluent, was agreed upon. Provision is also made, however, for chlorination of the sand filter effluent. Each sand filter unit has an area of about ⅚ acre, and a depth of 2½ feet of sand and 6 to 12 inches of broken stone; and is divided into halves by a wooden partition. Each contact filter is directly connected to a sand filter unit, so that the sand filter unit is dosed as the contact filter is automatically discharged. The flow may be diverted to either half of the sand filter, thus obtaining better distribution. The plant was designed for a population of at least 20,000; thus giving a loading per acre of sand filter of about 3000 people. The plant is not yet in service due to causes not connected with the plant itself.

10. Odors.—As regards odors, well designed and operated intermittent sand filters ordinarily give results satisfactory to state boards of health. The greatest source of odor is the

accumulation of sludge collected on the beds during the winter, which must be allowed to dry for several weeks in the spring before removal. Although sand beds are frequently operated adjacent to highways and dwellings without giving offense, it is prudent to locate disposal works of this type as far as practicable from residential districts.

11. Disadvantages.—With the advent of trickling filters and later of the activated sludge process, the greater cost of the intermittent sand filter process has become a serious drawback. Even in Massachusetts, Fitchburg adopted trickling filters, Brockton installed trickling filters instead of extending its sand filter plant and Worcester has very recently replaced its sand filters with trickling filters. A further tendency to curtail the use of sand filters has resulted from the development of chlorination for the elimination of objectionable bacteria. Moreover, the more vigilant supervision of operation of sewage treatment works by state authorities has disclosed many sand beds with surfaces so clogged at times that the sewage either is bypassed or overtops some low place in the surrounding embankments. While this condition has been generally overlooked in cases where the effluent passes to streams not used for water supply, its occurrence becomes more serious as streams are more and more used for this purpose, even though the performance of sand beds during the warmer seasons of the year is very satisfactory.

CHAPTER XXXIV

CONTACT FILTERS

1. Description.—This method of treatment consists in applying sewage to 4- to 6-foot of depth of broken stone or similar material in a tight tank or basin so as to fill the voids; permitting the sewage to remain in contact with the filter material for a short time, and then drawing off the effluent and allowing the filter to rest for a considerable time with the voids full of air before applying the next dose.

The action which takes place in contact filters is more complicated than that in intermittent sand filters. The efficiency of contact filters depends upon the retention within the filter of finely divided organic matters, particularly of a colloidal nature, under such conditions that these matters do not pass out in the effluent until their putrescibility is materially reduced; and upon maintaining the surfaces of the filtering particles in such a condition that biochemical developments may proceed advantageously. As much fine material must be retained as is feasible without serious clogging; and frequent aeration is necessary in order that oxygen may be absorbed by the films which form upon the surfaces of the filter material and thus through biochemical agencies oxidize the organic matter in the sewage as it passes over the films. If no oxygen, either from the air or from nitrates within the filter, is present, anaerobic action quickly occurs and may lead to serious consequences.

2. History.—Coarse-grained filters operated on the fill-and-draw plan, usually called contact filters, were first studied in 1892 at London by Binnie, Crimp and Dibdin. These studies were an outgrowth of the studies of gravel filters made by the Massachusetts State Board of Health at Lawrence. Beginning in 1893, with the construction of a 1-acre unit at Barking, contact filters were adopted at many places in England, the largest installation being the 120 acres of beds at Manchester. In this country they were little used prior to 1900, although by 1905 there were about a dozen municipal plants in service.

The introduction of this process was due to an endeavor to secure a higher rate of treatment than was possible with sand filters. For the same reason, however, they gave place in turn to trickling filters and are now almost entirely superseded in England by other processes, although in this country they still find a limited field of usefulness.

3. Rates.—Contact filters ordinarily give a non-putrescible effluent when treating from 125,000 to 150,000 gallons per acre daily per foot of effective depth of filter material. When free from clogging they may work temporarily at appreciably higher rates. In general they may be operated for short periods at rates much in excess of the average daily capacities. The rate secured with weak American sewages, however, seldom exceeds that with strong European sewages.

4. Efficiency.—Preliminary clarification of the sewage is necessary in order to avoid clogging of contact filters. With suitably clarified sewage, the removal of applied organic matter generally runs from 60 to 80 per cent. When the filter material is of an average size in excess of about 1 inch, it is found that, although the effluent as a whole is stable, the solids in the effluent will decompose and gasify when separated from their share of the liquid. With such coarse material it is necessary to pass the effluent through a final settling tank, which it is not necessary to use with fine material. Although bacterial removal may under some conditions reach as high as 70 per cent, the usefulness of the process lies in reduction of putrescibility rather than in removal of organisms of disease. The effluent from fine-grained contact filters is fairly clear. This is not true, however, with coarse-grained material as large as 1 to 1½ inches, which unloads solids requiring final settling tanks.

5. Construction Features.—Filter material should be hard stone or slag, of as uniform size as possible so as to provide a maximum of voids. Early experiments indicated sizes of 0.25 to 1.0 inch as best adapted to the purpose; but such material, although efficient, was found to clog badly, necessitating frequent removal and cleaning. Sizes of 1.0 to 2.5 inches have given satisfactory results. False bottoms of half-round tile are desirable. Suitable distribution of sewage is best accomplished by means of pipes laid just below the filter surface and having branches at intervals. Dosing is best done by automatic siphons, which also provide means for controlling the retention period.

Contact filters are generally arranged in groups, to be filled and discharged in rotation. When two sets of beds are arranged to operate in series, they are called double contact filters. Double contact filters are more efficient, but single contact filters take less head and cost less.

6. Operating Features.—Contact filters operate most satisfactorily with fresh, settled sewage. The rate of filling is not important. The contact period should not exceed say ½ hour, to avoid anaerobic action. Draining should be as rapid as consistent with reasonable retention of suspended matter in the filters. The resting period should be as long as practicable, in order to provide ample aeration and oxidation. New beds require several weeks for needed films to be formed on the surface of the filter material.

Filters of relatively fine material continually lose capacity due to clogging, and the material must be removed, washed, screened and replaced every 3 to 5 years. Filters of coarse material do not require such cleaning. Winter conditions do not seriously interfere with the operation of well managed filters; but, where filters are fed from the top, surface clogging may cause the applied sewage to freeze during severely cold weather.

7. Advantages.—In comparison with trickling filters, with which they are most usually brought into competition, contact filters have several advantages. They require less head for operation, thus avoiding pumping such as would be required in some cases by trickling filters. They are practically free from odors and flies. The sewage need not necessarily be exposed to view. Hence they are desirable where isolated sites are difficult or expensive to obtain. Since they operate satisfactorily at extremely varying rates, they are also advantageous for residential and institutional plants.

8. Disadvantages.—In operation, contact filters frequently give trouble due to clogging, unless the filtering material is coarse, requiring final settling tanks. On account of the operating expense thus incurred, but particularly on account of their much lower operating rate and consequent greater cost of construction, the contact filter method has largely given place to the trickling filter method in recent projects, although they produce effluents equally as good.

CHAPTER XXXV

TRICKLING FILTERS

SYNOPSIS

1. Description.—Trickling filters, frequently called sprinkling or percolating filters, are artificial beds of broken stone or slag, usually from 5 to 10 feet deep. Over them sewage is intermittently distributed as uniformly as possible in a well comminuted form; usually, in this country, as a spray. The beds are thoroughly underdrained and have tight, smooth floors of concrete. Recent installations also have tight walls.

2. Process.—Trickling filters require preliminary treatment of the sewage, either by sedimentation or screening. The filtering material becomes coated with organic matter upon which certain bacteria thrive and produce gelatinous films. Suspended and colloidal matters gather on these films and are changed by bacterial or enzyme action into more stable substances. The sewage as it enters the beds contains substantial amounts of atmospheric oxygen, and purification takes place very rapidly. Trickling filters periodically unload the suspended matter which they intercept, and hence must be followed by settling tanks.

3. Extent of Use.—For 20 years or more trickling filters have been constructed in the majority of cases where reasonably complete treatment was required. Within the past few years, however, the activated sludge process has been selected in preference to them in some instances.

4. Capacity.—The capacity of trickling filters is affected very substantially by the strength of the sewage; and hence, disregarding the effect of possible trade wastes, capacity is best expressed in terms of connected population. Deep beds are also considered by some to be somewhat more efficient per foot of depth than shallow ones; but, in general, with well settled domestic sewage each foot of depth of a 1-acre filter is sufficient for a connected population of from 3000 to 4000. With screened sewage or combined sewage the capacity is somewhat less than with domestic sewage.

5. Efficiency.—Trickling filters are able to produce an effluent which is non-putrescible. When they are followed by final tanks, the settled effluent is reasonably well clarified. They are also able, in connection with suitable sedimentation of both influent and effluent, to reduce the bacteria 90 per cent or more, and by 80 to 85 per cent the biochemical oxygen demand, of the crude sewage.

6. Advantages.—Trickling filters afford one of the cheapest available methods of producing a stable effluent. In conjunction with suitable final tanks the removal of suspended matter is satisfactory. They are inexpensive to operate, and they seldom become clogged.

7. Disadvantages.—Flies which breed in trickling filters are a serious nuisance at and closely adjacent to the plant. Odors are generally noticeable and may be serious where septic sewage is discharged upon the beds as a spray. On this account expense is often necessary to convey the sewage to an isolated site for treatment and to provide relatively large areas of land. Pumping is frequently necessary in order to obtain the necessary head, which exceeds that of any other method.

8. Present Status.—Trickling filters are still very widely and satisfactorily used where a stable effluent is required. Due to more uniform application of the sewage, greater loadings of sewage than formerly used have been found feasible. Better means for control of nuisances due to flies and odors have been found. Trickling filters are now encountering competition from the activated sludge process, which produces a clearer effluent and is usually less expensive to construct. They are, however, cheaper to operate, exclusive of pumping, and require less skilled attention than the newly developed activated sludge process.

HISTORY

Investigations by the Massachusetts State Board of Health should be credited with laying the foundation for modern coarse-grained filters. Starting in June, 1889, two experimental filters having comparatively fine gravel were operated at Lawrence. Nitrification was obtained, with more or less clogging. Large-scale development of this discovery of the feasibility of coarse filter material, more particularly as to spraying for aeration and better distribution and as to the use of false bottoms to overcome

bottom-clogging, is due principally to Corbett, of Salford, England. Hazen and Waring in America and Lowcock, Ducat, Scott-Moncrieff, Whittaker and Stoddard in England added much to the knowledge of the subject.

The first modern municipal trickling filter plant in this country was designed in 1905 for Columbus, Ohio, but the first put in operation was at Reading, Pa., in 1908. Early examples of this type are those at Washington, Pa., Mount Vernon, N. Y.,

FIG. 49.—Aerial view, Baltimore sewage treatment works.

and Baltimore, Md. (See Fig. 49.) Since 1910 practically all large American works requiring a finishing treatment except those at Houston, Tex., have been of this type up to 1925, when the activated sludge plants at Milwaukee and Indianapolis were completed. Trickling filters, however, have been quite recently adopted for Worcester, Cleveland, Chicago (Calumet) and Fort Worth, in this country, and at Leeds and Bradford in England.

Trickling filters represent one of the greatest advances in sewage treatment.

ACTION OF THE TRICKLING FILTER

When settled or finely screened sewage is applied to a well matured trickling filter bed, remarkable changes take place both in its physical and chemical properties during the relatively brief passage of the liquid through the coarse stones. The finely suspended and colloidal material is replaced with coarser flocculent matter which readily settles out. The odors characteristic of the applied sewage are eliminated. Chemically there is a great reduction in organic content, accompanied by the building up of nitrates. The effluent after settling is stable and non-putrescible. A considerable reduction takes place in the bacteria of the intestinal type present in the sewage. In brief, passage through the bed produces within a few minutes all the effects of aerobic decomposition which, under natural conditions, might require weeks to accomplish.

These effects are not due to filtration in the ordinary sense, but to the presence on the stones throughout the bed of a gelatinous film of living organisms, without which the filter cannot function.

Various experiments from time to time have shown that cultures of special bacteria, organic solutions, coloring matters and other substances, when added to a trickling filter, are adsorbed by the film and either do not appear in the effluent or appear only after the lapse of many hours or days. This demonstrates that the flow is not directly through the bed, but by displacement of adsorbed films of previous doses.

The trickling filter is a highly complex community of plant and animal life with varying characteristics according to season and depth in the bed. Frequently the surface stones are covered with green and blue-green algae or yellow fungi. Chief interest centers in the film or coating of the stone throughout the bed, because in this film are located the activities peculiar to the process. This slimy film, which in new filters requires some weeks to build up to a point of efficiency, consists of a mass of bacteria, fungi, protozoa, worms, insect larvae and other small life.

Bacterial Population.—The primary decomposition of organic matter by the filter is due to the bacteria living in the film and to the bacterial enzymes contained in the treated sewage. The presence in the film of nitrifying bacteria which oxidize ammonia to nitrite and nitrate has been demonstrated repeatedly since the early experiments of the Massachusetts Board of Health. It is also well recognized that a substantial percentage of intesti-

nal bacteria is eliminated during passage of sewage through the filter. Recent work (1922 *et seq.*) of the New Jersey Agricultural Experiment Station on the Plainfield plant has made clearer the activities of other bacterial groups. The dominant bacteria in the film and effluent of a trickling filter are of the same species as in the applied sewage, as distinguished by their power to decompose protein, produce hydrogen sulphide and reduce nitrates and sulphates. An increase of these forms was found with increased depth in the bed, except for the hydrogen sulphide producers which decreased. Bacteria capable of oxidizing sulphur and nitrogen compounds were found to increase in the lower depths of the bed although never numerically as great in the effluent as those forms which have reducing powers in the absence of oxygen. This preponderance of reducing bacteria was not found to affect to any serious extent the efficiency of the filter as an oxidizing device, as oxygen is normally present in it.

Non-bacterial Population.—Besides the bacteria, other organisms occur abundantly in the film, although little definite information is available as to their relation to purification. The algae and fungi on the top stones undoubtedly are related to clogging and pooling sometimes noticed. The fungi and filamentous bacteria occurring throughout the bed, aside from their ability to feed on organic matter, are useful as a supporting surface for bacterial growth and moreover serve to trap and hold suspended particles. Some of the protozoa, particularly the ciliated forms, occur in great abundance although their significance has not been clearly established. Worms often occur in great numbers and the seasonal sloughing of the filter film has been attributed to their activities. The same is true of the larvae and pupae of the moth fly which live in the film. The adult fly frequently becomes a nuisance in the vicinity of trickling filters.[1]

PRACTICAL OPERATING FEATURES

Climatic Influence.—Uncovered trickling filters are used successfully in the latitudes of northern United States and even in Canada, and Scandinavia, though with a certain amount of trouble on account of ice coating. Even when clogging of the

[1] For further discussion of the non-bacterial population the reader is referred to Fuller's "Sewage Disposal," McGraw-Hill Book Company, Inc., 1912; to a brief review by Cox, Eng. News-Record, 1921, Vol. 87, p. 720, and especially to the various published results of the New Jersey Agricultural Experiment Station.

surface by ice does not exist, the efficiency of the filter is somewhat lower in winter than in summer and this factor must be reckoned with in providing capacity. In the colder climates covers are sometimes provided. Gloversville and Mt. Vernon, N. Y., are instances.

Intermittent Dosing.—The application of sewage intermittently is in general unnecessary because with few exceptions the sprayed sewage is 60 to 80 per cent saturated with atmospheric oxygen, which is ordinarily sufficient for maintaining activities on the bed on an aerobic basis. In practice, however, the dosing is usually done intermittently by means of automatic siphons or mechanical dosing devices. The chance of nozzle clogging is lessened by the higher rate of intermittent flow and distribution is better.

Resting for short periods is seldom advantageous except where the filters are greatly overloaded. Resting has been used to some extent to relieve surface clogging, but if continued for more than a few weeks the active film may be destroyed. Keeping the bed out of service in winter is also detrimental.

Clogging.—Clogging of the surface, with resulting localized pooling, reduces the capacity of the filter and impairs the quality of effluent. Clogging may be due to too fine material or to inadequate preliminary treatment, but is more often caused by a felted mat of algae and fungi in the top layers. Various expedients have been used to correct surface clogging. Resting the filter long enough to allow drying is usually successful. In aggravated cases it is necessary to turn over the top layer by harrowing or forking. Chlorination of the applied sewage has been reported as helpful in keeping down the surface growths, although it is obvious that caution must be used against dosing to the point of destroying the active film in the deeper portion of the bed. In several places in England and at Glasgow artificial propagation in the filter bed of a wingless insect, known as *Achorutes viaticus* (the water spring-tail), has been reported as successful in preventing clogging. Attempts have also been made to transport cultures of this insect to filter beds in Chicago, Stockholm, South Africa and India. *Achorutes* is stated to feed upon the mold mycelium in the top layers and is destroyed by submergence. A description of the British experiences, together with notes on the propagation of the insect, will be found in the Surveyor for 1921-22-23 and the Engineer for 1922.

Clogging of nozzles is due to inadequate preliminary treatment to remove scum and floating solids and has been lessened by fine screens at Baltimore and elsewhere.

Flies.—Most conspicuous of the insects about trickling filters is the tiny filter or moth fly (*Psychoda alternata*). It breeds in the filters throughout the warm months and at times becomes very pestiferous to attendants and nearby residents, although it does not bite. Its small size enables it to penetrate ordinary mesh window screens. Ordinarily it is restricted to a hundred feet or so from the filter, but it may be windblown to distances of ½ to ¾ mile. Headlee, who studied the fly at the Plainfield plant (Jour. Economic Entomology, 1919, Vol. 12, p. 35) established the following facts regarding its life history. *Psychoda* may be found in the bed throughout the year, reproduction being noted in December. It is most abundant in the spring and fall and in the zone from 3 to 12 inches below the surface. Eggs are laid in the film surrounding the stones. Larvae feed in the film and the pupae remain there until emergence of the adult fly. The minimum life cycle is 12 days in summer, with an average of 2 weeks between broods. All stages of the fly were found to occur most abundantly when a thick film existed on the stones.

Flooding.—Headlee found flooding of the filter beds for 24 hours at weekly intervals to be an effective means of control of the moth fly, and this method has been followed at Plainfield and other places successfully for many years.

Flooding is sometimes not feasible on account of open construction of beds or by reason of the plant being overloaded to a point where the beds cannot be put out of commission for a period of 24 to 36 hours.

Chlorination.[1]—Some success has been had in controlling the fly by application of hypochlorite or chlorine to the applied sewage. This method must be used carefully, however, to avoid damage to the usual functions of the filter.

Orthodichlorbenzene.—This has been used successfully as an insecticide on the beds at Rochester, Schenectady and elsewhere.

Unloading.—The active film on the filter stones varies much in consistency and thickness throughout the year. One characteristic of the trickling filter is the periodical "unloading" or sloughing of the film. Usually in the spring and fall unloading seems to be related to the activity of larger organisms like worms and

[1]See Chap. XXIX on Chlorination; Cohn's Report for Schenectady, 1925; Eddy, Mohlman, Rudolfs, Clark and Cohn, *Eng. News-Record*, Vol. 96, June 10, 1926, p. **943**; June 24, 1926, p. 1035; Vol. 97, July, 8, 1916, p. 74.

fly larvae and these forms at times of unloading are washed out of the filter.

Unloading may be produced artificially by the application of chemicals such as chlorine, copper sulphate, or caustic or by allowing the filter to stand flooded until putrefaction takes place.

To prevent gross impairment of the effluent, especially during times of unloading, it is necessary to follow trickling filters with final settling tanks with 1.5 to 2.5 hours retention in order to remove settleable solids. These tanks are described in Chapter XXXVI on Final Settling Tanks.

Odors from Trickling Filters.—Since the process requires the discharging of sewage into the air as a fine spray, the trickling filter is not free from odors. Their character and intensity depend greatly upon the freshness of sewage, the protection from winds by surrounding topography, trees or covers, and the weather. Odors are most noticeable on warm damp days with a light wind blowing. Fresh sewage has an odor, suggestive of laundries, which is neither very offensive nor intense. Odors from sewage in an advanced stage of anaerobic decomposition may be very offensive at some distance.

Intensive odors from trickling filters, at relatively great distances, occasionally result from a combination of circumstances occurring only a few times yearly, when ordinarily they are not noticeable more than 100 yards away. At Reading, Pa., with preliminary treatment by septic tanks, odors are seldom perceptible at distances of more than 100 yards. At Columbus, Ohio, when treating septic sewage, the odors were always noticeable at 300 yards and sometimes 900 yards away. At Plainfield, N. J., with comparatively stale sewage, there is very little odor, yet on a few occasions it has been detected 800 yards away. At Schenectady, N. Y., where the sewage is ordinarily not septic, witnesses testifying in a damage suit stated that 100 feet was the limit of noticeable odor. At Mount Vernon, N. Y., with covered filters treating fresh sewage after 4 hours retention in a septic tank, there is practically no odor about the plant, yet on warm, damp nights odors are often discernible for ½ mile. At Baltimore, there have been complaints about odors, but it is hard to tell whether they arise from the filters, from inadequate sludge digestion or from decomposition in the settling tanks.

At Chicago, the activated sludge process was adopted for the large North Side plant, on account of inability to provide a ½

mile wide strip for isolation of the filters; while for the still larger West Side and South Side plants, where there is isolation, trickling filters have been proposed.

In general, small trickling filter plants should be located at least 1/8 mile from built-up streets. For moderate-sized plants 1/4 mile is preferable; and for very large plants 1/2 mile is advisable. With sewage showing anaerobic decomposition, these distances may well be increased.

Chlorination of sewage prior to settling or prior to dosing filters has been suggested as a preventive of odors released by the spray. The relatively large doses required add considerable expense to treatment, but may be justified in some cases. However, caution must be used under the circumstances to avoid interfering with filter activities.

PRELIMINARY TREATMENT

Preliminary treatment to an extent greater than to guard against nozzle and surface clogging depends upon local requirements. When fine screens alone are used, an increase in filter area or depth of about 25 per cent will be necessitated as compared with that required when adequate settling tanks are employed. Settling tanks are efficient in removing suspended matter, but do not protect the nozzles against fairly coarse suspended particles unless the tanks are equipped with adequate scum boards. Septic tanks are unsatisfactory on account of of odors. After chemical precipitation, perhaps 30 per cent more of the effluent can be treated on the same area than with settled sewage.

The decision between extra tankage and extra filter capacity rests upon conditions as to strength of sewage, purity of effluent required, nuisance from odor and cost. Reference is here made to experiences at Birmingham, England, with activated sludge (see Chapters XXXVII–XXXVIII).

FILTER MATERIAL

In selecting filtering material chief consideration should be given to permanency and size, and, to a less extent, to roughness. Depending upon availability and cost, coke, cinders, gravel, slag, coal, corncobs, faggots (brush) or broken stone are used. Coke and cinders are of little value because they disintegrate easily and become clogged. Gravel is too smooth to permit ready bacterial growth. Slag and hard broken stone are in every way suitable.

Theoretically rough material is advantageous, but growths and deposits soon smooth out the irregularities. When starting a filter, particularly in winter, rough material may be of real advantage.

CAPACITY

The capacity of trickling filters to purify sewage depends upon the strength of the sewage; the kind of sewage, whether separate or combined; the amount and kind of trade waste present, if any; the preliminary treatment given; the size and depth of the filtering material and in a measure upon the quality of effluent desired.

Rates of treatment in America are roughly thrice those in Europe, where the sewage is about thrice as strong. Other things being equal, this type of filter seems capable of handling an approximately constant number of units (measured either by the total unoxidized nitrogen or by the biochemical oxygen demand) of organic matter, per unit area or per unit volume of material, regardless of dilution within the limits usually encountered.

An average rate for ordinary domestic sewage, of about 100 gallons per capita daily, is about 2 million gallons daily per acre on a filter of 6-foot depth; or, about 3000 persons per acre per foot of depth.

At Columbus, with combined sewage, the 5-foot beds of ½- to 2-inch stone were rated at 400,000 gallons daily per acre foot. At Baltimore, beds of 8½-foot depth of 1- to 2½-inch stone were designed on the basis of about 300,000 gallons daily or about 2400 persons per acre foot. At Plainfield, N. J., with domestic sewage, beds of a 6-foot depth of 1- to 2-inch stone were designed for a loading of about 380,000 gallons daily or 3800 persons per acre foot. At Gloversville, N. Y., where there is much tannery waste, a rate of about 200,000 gallons daily per acre foot was recommended, with 5-foot beds. At Worcester, Mass., where trickling filters have recently been put into service, the 10-foot beds of 1¼- to 3-inch stone were designed for 200,000 gallons daily or 2000 persons per acre foot. The Worcester sewage is combined sewage containing acid wastes from steel mills and some tannery wastes. At the Cleveland Southerly Works, under construction in 1925 to treat combined sewage, the 10-foot beds of 2- to 3-inch stone are rated at 580,000 gallons daily or 4000 persons per acre foot.

Experiments at Lawrence, with filters of fine material, 0.75 to 1.50 inches in size, showed that deep filters were somewhat

more efficient than shallow ones. With equal nitrification and stability results, it was stated that the quantity which could be suitably filtered per acre foot varied from 116,600 gallons for 4-foot depth to 350,000 gallons for 10-foot depth. Deep filters are somewhat more economical to construct per unit of volume than shallow ones, but operating costs due to additional pumping, surface clogging and the effect of poorer ventilation at times of surface clogging may to some extent balance this. The authors adhere to their practice of building beds ordinarily of a depth of about 6.5 feet.

The British Royal Commission on Sewage Disposal has stated that practically the same purification will be obtained from a given quantity of coarse material, whether the beds are deep or shallow, within reasonable limits.

The requirements of the British Ministry of Health, converted into American units, regarding the rate of dry weather flow per acre foot of trickling filter composed of material which will not pass a 1-inch screen are given in Table 62. Such filters may be used for storm flows up to three times the dry weather flow. In this connection it should be remembered that weak British sewage is much stronger than American sewage.

TABLE 62.—GALLONS DRY WEATHER FLOW PER ACRE FOOT ALLOWABLE FOR TRICKLING FILTERS
(British Ministry of Health Requirements)

Preliminary treatment	Character of sewage		
	Strong	Average	Weak
Grit chamber	29,000	48,500	77,500
Plain sedimentation or septic tank	87,000	136,000	194,000
Chemical precipitation	126,000	194,000	290,000

EFFICIENCY[1]

The effluent leaving the filter should have as a yearly average about the same amount of suspended matter as the original

[1] A Bacteriological Study of a Sewage Disposal Plant, William H. Gaub, Jr., Bull. 394, N. J. Agricultural Experiment Stations, March, 1924. Operations of Baltimore Sewage Works, 1920 to 1925. Keefer, Eng. News-Record, Vol. 97, p. 174, July 29, 1926. Engineering Board of Review, Sanitary District of Chicago, Part III, Appendix I, Sewage Disposal. February 21, 1925.

TABLE 63.—EFFICIENCY OF TRICKLING FILTERS AS SHOWN BY ANALYSES
(Parts per Million, Except as Shown)

	Fitchburg, Mass., 1923–4				Schenectady, N. Y., 1923		Baltimore, Md., 1912–0 inc.			Brockton, Mass., 1924		Columbus, Ohio, 1924		Gloversville, N. Y., 1922	
	Dec. to May		June to Nov.												
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf. A	Inf. B	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
Ammonia															
Free	12.	3.6	16.2	3.9	13.8	6.8	...	...	......	31.2	16.4	......	..	14.6	12.5
Albuminoid total	3.	1.8	3.4	1.7	3.1	2.9	...	...	......	12.7	7.7	......	..	9.7	7.5
Albuminoid dissolved	2.	1.1	2.2	1.1	1.9	0.9	...	...	......	7.6	5.9	......		7.0	4.3
Nitrites	0.08	0.17	0.01	0.11	......	0.74	...	...	......	......	0.77		3.4	..	0.98
Nitrates	0.76	7.64	0.24	11.67	......	4.99	...	...	......	......	15.80			..	1.38
Oxygen consumed															
Total	83	59	114	73	......	......	...	...	......	140	59	......	..	152	124
Dissolved	49	29	63	38	......	......	...	...	......	99	42	......		131	104
Solids															
Total	302	289	409	375	454	431	...	...	......	616	457				
Volatile	150	139	195	171	......	......	...	...	......	354	199				
Suspended	44	38	58	39	53	65	79	...	68	174	58	82	63	134	139
Biochemical oxygen demand	......	......	......	......	......	......	110	132(a)	34	......	......	224	52		
Relative stability, per cent	......	......	......	......	......	......	...	...	91	......	96.5	7.4	39		
Bacteria per cubic centimeters															
Total at 37° C., thousands	......	......	......	......	......	......	817	575(a)	283						
Acid formers	......	......	......	......	......	......	77	98(a)	23						

NOTE.—Data of Fitchburg, Schenectady, Brockton and Columbus from Annual Reports. Baltimore from Eng. News-Record, 1921, vol. 87, p. 97. (a) First 6 months only. Gloversville from Public Works 1923, Vol. 54, p. 199; results cover second half of year only.

TABLE 64.—AVERAGE ANALYSES OF INFLUENTS AND EFFLUENTS OF TRICKLING FILTERS*
(Results in Parts per Million, Except as Noted)

City	Suspended matter			Oxygen consumed, 30 minutes in boiling water			Alkalinity as $CaCO_3$ by methyl orange			5-day oxygen demand			Nitrates in effluent
	Inf.	Eff.	Per cent removed	Inf.	Eff.	Per cent removed	Inf.	Eff.	Per cent removed	Inf.	Eff.	Per cent removed	
Atlanta (Intrenchment)	67	42	37	21	10.0	52	82	48.0	41	23	4.2	82	3.1
Atlanta (Peachtree)	68	38	44	18	7.0	61	69	35.0	49	20	3.9	81	2.1
Baltimore	107	46	57	36	14.0	61	144	63.0	56	125	14.0	89	3.3
Columbus	79	81	−2	46	28.0	39	219	192.0	12	134	49.0	63	0.6
Fitchburg	63	52	17	37	19.0	49	99	7.9	92	95	20.0	79	5.2
Lexington	67	40	40	22	11.0	50	194	152.0	22	87	16.0†	82	
Reading	85	48	44	31	16.0	48	177	105.0	41	96	20.0	79	4.4
Rochester (Brighton)	40	29	28	15	9.7	35	189	131.0	31	36	7.1	80	2.8
Average	73	47	33	28	14.0	50	147	92.0	39	77	17.0	79	

* U. S. Public Health Service, Public Health Bulletin, No. 132.
† Effluent secondary sedimentation tanks.

sewage, otherwise the filter would become clogged. The suspended matter is however reduced to a fairly coarse, flocculent condition and readily subsides in settling basins. Trickling filters produce a stable, non-putrescible effluent at much higher rates than possible with other types of filters, and without clogging. Absence of serious clogging after even 15 to 25 years of service is one of the outstanding characteristics of this type of filter.

Ordinarily trickling filters will reduce the biochemical oxygen demands (5 day test) of sewage between 80 and 85 per cent, whereas the bacterial reduction by such units is likely to average 90 per cent.

Typical operating results of representative American installations are given in Table 63.

The data reported in Table 64 are the result of analyses made on the ground of samples collected during a 10- to 15-day period by the U. S. Public Health Service.

CONSTRUCTION FEATURES

Size of Filtering Material.—While theoretically filtering material should be fine in order to present a greater surface area, practical experience has shown that large stone is preferable in order to reduce clogging, to permit disgorging of retained solids and to allow proper circulation of air. But the stone must be fine enough to retard the velocity of flow sufficiently to allow time during which the matters to be purified are held in contact with the bacterial films. Material screened between 1½- and 2½-inch circular openings is generally most suitable. In many filters larger stone is used at the bottom, surrounding the underdrains.

Depth of Filtering Material.—The depth of filter material has been discussed under Efficiency. Under all but very unusual conditions it should be not less than 5½ or more than 10 feet, exclusive of underdrains. Probably about 6½ feet represent prevailing practice.

Site.—The choice of location depends upon ease of delivery of the sewage to and discharge of the effluent from the site; isolation, as compared to cost of utilizing less adaptable land and purchasing nearby property; access for construction and operating purposes, and the cost of adapting the works to the physical character of the site. Isolation is important from the standpoint

of possible damage suits, and from the possible necessity of later removal should unexpected growth of neighboring population demand it.

Form of Filter.—Topography influences largely the form and size of filter units; but for filters with fixed nozzles, rectangular units offer the best shape for distribution and collection of sewage. Large filter units have sometimes been divided by galleries in which valves for controlling the flow are placed. The influent piping for large units should be sufficiently subdivided so that small sections of the filter may be put out of service for cleaning, repair or flooding without requiring excessive rates elsewhere.

Walls.—Practically watertight masonry walls are preferable to provide flooding. Earth banks and floors wash into the filtering material and produce clogging and loss of ventilation. Timber construction decays and produces odors. Omission of walls in filters built above ground produces only local ventilation, and adds to the area of floors and underdrains needed to support the slopes of the filter material. Dry rubble or slag walls do not add appreciably to the ventilation. Where filters are built in cut or banked around with earth, the walls may be made vertical and heavy enough to withstand water and earth pressure. A more economical construction is to slope the earth and cover it with a thin layer of concrete, which may be of precast slabs, of reinforced concrete laid in place, or of cement plaster on metal lath.

Floors.—Tight sloping floors, with hard, smooth, watertight surfaces, are necessary. Four inches of plain concrete are generally sufficient, with reinforcement or greater thickness where the earth foundation is poor. Channels and drains must be smooth, and floors should have a slope of at least 1 per cent toward the main drains.

Drainage System.—Floor drainage is often provided for by laying half-round tile, convex side up, with edges embedded in the mortar surface of the floor, as shown in Fig. 50. Such construction allows the sewage to spread in a thin film over the entire floor, thus tending to cause stranding of solids, and also provides V-shaped spaces between the tile in which solids may collect. But this is the cheapest construction and has given no trouble in the oldest filters in this country. At Baltimore, Fitchburg and Worcester grooves were cast in the concrete floor, covered with slotted tiles or slabs at Baltimore, and with narrow concrete cross-beams spaced 1⅛ inches apart, at Fitchburg and

Worcester. The Worcester filter bottom is shown in Fig. 51. At Kings Park, N. Y., precast tapered slabs placed on the filter

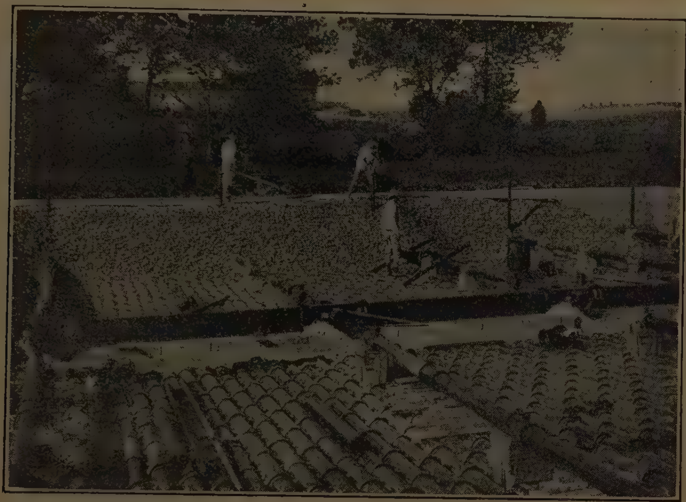


FIG. 50.—Underdrain system, Bridewell, Md.

FIG. 51.—Underdrain system, Worcester, Mass.

floor formed grooves over which tiles spaced 1 inch apart were placed. At Batavia, N. Y., a special vitrified block, acting both as a floor and as a collecting system, was used.

Sometimes floor tiles or channels have been carried through the walls for flushing and ventilating purposes. Such construction has been found helpful, but it precludes the possibility of flooding to destroy flies or remove stored growths.

Ventilation.—To provide maximum purification, a certain amount of oxygen must be present at all times and all places within the filter. Such condition depends mainly upon movement of the air downward through the pores of the filter and out through the underdrains. With deep filters extra precaution is needed in securing filter material of permanent character and sufficient size, and in the laying of the bottom courses and the construction of the drainage system so that sufficient air will circulate to provide oxygen in the lower part of the filter.

Forced ventilation through revolving cowls connected by pipes to the underdrains and ventilation through open side walls or through the omission of side walls are of little value and reduce bacterial activity in cold weather. The natural downward current of air has always been found sufficient, except that sometimes slight troubles have been experienced with fine filter material. Clogging matter in filter material on the floors and in the underdrains, which tends to interrupt free circulation of air, is detrimental, but may be removed by flushing or flooding.

Distribution.—In this country the sewage, after preliminary treatment, is applied as a spray through fixed sprinkler nozzles. In order to distribute the sewage uniformly over the surface the head on the nozzles is caused to vary, occasionally by the use of undulating valves, but most frequently by the use of dosing tanks and siphons. The rate of application therefore varies, and with single siphons must always be greater than the incoming rate; while with the revolving or travelling distributors used largely abroad the discharge rate is the same as the incoming rate.

With siphons, starting with the dosing tank full, the spray under maximum head has a maximum reach which gradually contracts until the siphon locks at the low head; after which the filter rests while the dosing tank fills. Alternating siphons are now frequently used. With these the incoming sewage fills one dosing tank while the other is being emptied; thus permitting the quantity discharged at any given head to be reasonably definite, and at the same time reducing the time interval between

doses. The undulating valve, which varies the head through a regular cycle by varying the amount of throttling of the influent pipe, provides continuous flow but requires the use of automatic devices for changing the throttling arrangements or throwing into service certain portions of the filters as the rate of flow of the incoming sewage varies.

Distribution Piping.—In the earlier trickling filters the influent lines were of vitrified pipe encased in concrete, laid near the bottom of the filter, with cast-iron risers to the nozzles. Cast-iron pipe influent lines laid near the filter surface are now generally used. Although these latter interfere slightly with the downward flow of sewage and are somewhat exposed to freezing, their use has not caused trouble, and they have distinct advantages as regards watertightness, inspection, cleaning and repair.

Filter Galleries.—Filter operating galleries, placed between main units to provide access to valves on distribution lines and to provide access to the underdrainage system for flushing, have been frequently provided, but in many recent designs have been omitted.

Nozzles, Dashplates and Distributors.—Sprinkler nozzles consist of an orifice in a dome or plate above which a cone-shaped spreader is rigidly connected. The Columbus nozzle, the first designed in this country, has a 9/16-inch orifice with a cone supported by two side arms. In later nozzles, such as the Taylor and Worcester nozzles, the spreader is supported by a spindle extending through the orifice; thus avoiding collection of suspended matter on the side arms, but obstructing the orifice slightly. These nozzles are shown in Figs. 52, 53 and 54.

Although nozzles have been designed and used which throw a square or a hexagonal spray, such nozzles do not ordinarily distribute the sewage so evenly as do those throwing circular sprays and are difficult to keep in alignment. They are now seldom used. Circular spray nozzles are placed at the centers of hexagonal areas, and are so spaced that the outer rings of spray overlap and thus somewhat compensate for the smaller volume of sewage per unit of area discharged under high heads. Uniform distribution of the sewage is not possible, although tapered dosing tanks and careful nozzle spacing and regulation of the head are helpful. Sewage normally passes directly downward through the bed, with very little lateral movement through the filtering material.

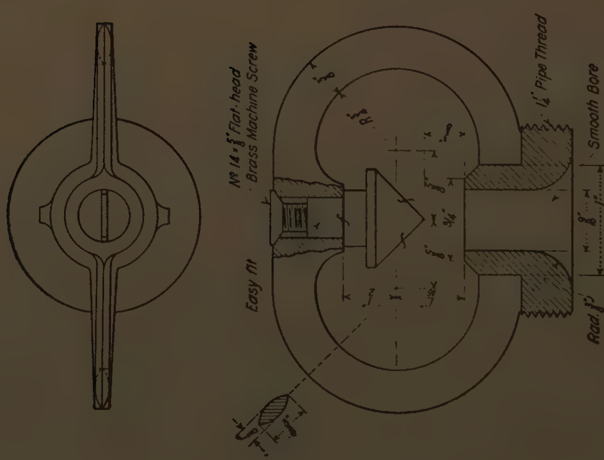


FIG. 52.—Columbus nozzle.

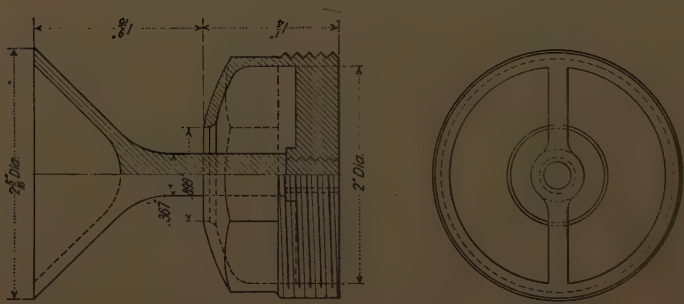


FIG. 53.—Taylor nozzle.

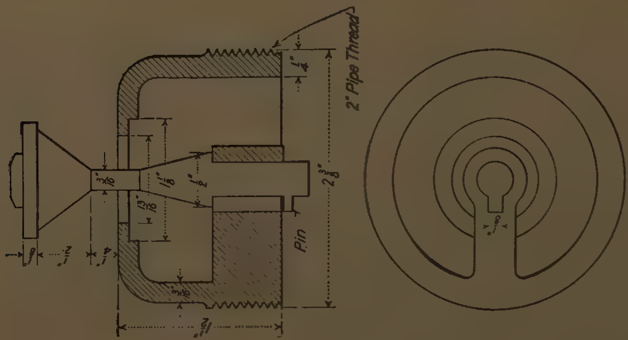


FIG. 54.—Worcester nozzle.

Nozzle Size and Spacing.—The available working head and the maximum inflow rate govern the size and spacing of nozzles. High and low heads may be somewhat adjusted, but the maximum head is of course limited by the sewage level in the preliminary tanks, sewer or dosing chamber. The most common spacing is 12 to 15 feet. With dosing by single siphons, the relation between low head and spacing and size of nozzles must be such that maximum rates of flow of incoming sewage will be exceeded at the low head, so that the dosing tank may empty and the siphon lock. Nozzles with small orifices may be installed for use when the filter is put into operation, and later reamed out to handle greater flows.

Fig. 55.—Trickling filters, Elizabethtown, Pa.

When nozzles are placed at the corners of square areas and their sprays just meet without overlapping, over 30 per cent of the filter will receive no sewage. Similarly, if the nozzles are placed at the apices of equilateral triangles, about 10 per cent will receive no sewage; but if the spacing and head are such that the sprays meet at points equidistant from adjacent nozzles, all the filter area will receive sewage and some parts will receive sewage from two nozzles. This overlapping is however advantageous as has been explained before. To avoid non-uniform dosing at the perimeter of filters, half-spray nozzles are sometimes used.

Head Required.—The total head between high level in the dosing tank and the filter floor at the underdrains should be at

least 12 feet for a filter 6 feet deep. To a head of 5 feet or more necessary at the nozzle must be added the depth of the filter material and underdrains, the slope of the filter floor and the friction in the influent piping. Nozzle spacing must be closer for lower heads, increasing the cost of distribution piping and nozzles. While reasonably satisfactory results have been obtained with a total head of $10\frac{1}{2}$ feet at Schenectady, a head of 15 feet is usually required, and more with relatively deep filters. In filters of an acre area or more, the friction loss to the most distant nozzle may be measurably greater than to the nearest nozzle. This has led in some cases to the sloping of the filter surface away from the dosing tank, but the practice is of doubtful value.

Dashplates.—This type of spray distribution provides for discharging sewage downward through nozzles in solid streams upon curved plates beneath. It is not as suitable as the nozzle type. Liability to freezing and effect of wind require housing of the filters. Clogging of the nozzle may divert the stream from the dashplate. Lack of proper adjustment between the nozzle and plate may cause poor distribution.

Travelling or Revolving Distributors.—In English practice both fixed nozzles and moving distributors are used, with principally the latter in recent plants. Moving distributors are of the revolving or the travelling type, sometimes operated by available sewage head. In the former, used with circular filters, perforated or slotted arms revolve about a central column; in the latter, slotted pipes or channels move back and forth on wheels over rectangular units. While mild winter conditions and the use of finer filter material and lower rates of application have made these devices successful in England, they have not been considered so suitable for American conditions as fixed nozzles. Rotating distributors with circular beds have been operated, however, at Pontiac, Mich., by Hubbell with success. Travelling distributors were installed by Potter at Springfield, Mo.

While the quantity applied per unit of area to all parts of the filter is practically uniform with travelling distributors, the actual rate and resting period vary greatly. With fine material this is not of great importance, but with the coarse material generally used in this country unusual depth would be required in order to provide sufficient time in passing through the filter. On the other hand, these travelling distributors are considered in Eng-

land to be helpful in keeping down odors, due to less exposure of the sewage to the air.

Permanency.—Trickling filters with masonry walls and floors and provided with hard stone or slag filtering material larger than 1 inch in size, cast-iron influent piping, brass nozzles and dosing siphons require little repair and little maintenance cost for replacing or cleaning material or underdrains.

CHAPTER XXXVI

FINAL SETTLING TANKS

SYNOPSIS

1. Description.—Settling tanks following previous steps in sewage treatment, generally called final settling tanks, are usually installed for the purpose of intercepting such suspended matters as would otherwise result in unsightliness or the formation of putrefying sludge banks in the waters into which they discharge. They are necessary in the activated sludge process to collect sludge for use in the aeration tanks as well as to separate the sludge from the clear liquor.

2. Types.—Final settling tanks may be of any of the types mentioned in Chapter XIX, Plain Sedimentation Tanks. The earlier tanks were usually shallow, flat-bottomed tanks. More recently hopper-bottomed tanks, hydraulically cleaned and mechanically cleaned types like the Dorr clarifiers have come into favor on account of greater ease in cleaning.

3. Origin.—Final settling tanks first came into use in England, where they were found necessary in connection with the development of trickling filters. Methods of purification used prior to the introduction of trickling filters, such as broad irrigation, sand filters and chemical precipitation, produced a clear effluent; and the earlier contact filters, constructed of fine material, retained the suspended solids to a large extent.

4. Capacities.—Detention periods of ¾ to 1½ hours are commonly used, although longer periods have sometimes been provided. The Ministry of Health requires 2 hours capacity based on dry weather flow.

5. Velocities.—Velocities in horizontal flow tanks should not exceed about ½ inch per second at maximum rates of flow. In vertical-flow tanks they should not exceed ¼ inch per second. Inlet velocities should be checked in order to avoid short-circuiting and bottom scour, as explained in Chapter XVIII.

6. Efficiency.—In general, with tanks for trickling filter effluents, it is feasible to remove from 50 to 70 per cent of the

suspended solids contained in filter effluents. With tanks for the activated sludge process a removal of 80 to 90 per cent of the suspended solids in the raw sewage is feasible.

7. **Cleaning.**—Methods of cleaning depend upon the type of tank used. Removal of sludge may be by draining and flushing, hydrostatic pressure or mechanical devices, as described in other chapters. Removal should take place before the sludge becomes gasified to such an extent as to appear in the effluent.

8. **Sludge Disposal.**—The sludge may be disposed of as undigested sludge or digested sludge, or may be used as fertilizer. For descriptions of these methods of disposal, reference is made to Chapters XX, XXVI and XXXIX.

9. **Present Status.**—Final settling tanks are always essential in the activated sludge process. They should be used after all trickling filters. They have been so used in all except a very few cases where local conditions, such as discharge into muddy waters, made their omission possible. They are sometimes used following coarse-grained contact beds, particularly where further treatment on sand filters is required.

DIFFERENCES BETWEEN PRELIMINARY AND FINAL TANKS

While the types of tanks used for final treatment and the rules governing their action are similar to those used for preliminary treatment, the objects sought and their manner of operation are not exactly the same. Preliminary tanks are used not only for clarifying the sewage, but also in many cases for reducing the volume of the solids separated from the sewage by digestion within the tank itself. Final tanks, on the other hand, are frequently installed for removing solids objectionable to sight, as well as those which might later by putrefaction cause a nuisance. They are relatively of small capacity as compared with preliminary tanks.

SLUDGE REMOVAL

With the old flat-bottomed type of tank the sludge was removed once in 6 weeks or more, depending on when the deposited sludge gasified so as to appear in the effluent. With trickling filter effluents entering tanks cleaned hydraulically the sludge is removed at least once a day. In the case of activated sludge continuous removal is necessary.

DEVELOPMENT OF TYPE

Early settling tanks in this country were generally relatively shallow rectangular horizontal flow tanks. The first Reading trickling filter unit put in operation in 1907 was provided with a final tank of this type, having a detention period of about 2.6 hours at average rates and was unusually successful in removing suspended matters. During the first few years of sedimentation tank construction it was the practice to clean the basins only when they become so overloaded with sludge or when gasification so lifted the sludge that objectionable amounts of suspended matters passed out in the effluent. The frequency of cleaning depended much on the season of the year, the character and volume of the sewage and the amount of room provided for the storage of sludge within the settling tank.

With the introduction of coarse-grained filters and the attention given to means of removing from the final effluent all gross suspended matters, study was directed toward the development of more efficient types of tank. It was not the economic aspect of the question, or the necessity of obtaining better results that brought this about, but rather the desire to provide structures with arrangements for cleaning the tanks readily without interrupting operations to a serious extent.

Among the first departures from the original flat-bottomed type were tanks similar to the vertical flow tanks used earlier at Dortmund, Germany. Later similar tanks of less depth and having a flow which is a combination of upward with radial or cross-flow were used in this country and in England. The final tanks used at Birmingham, England, and Fitchburg, Mass., described later in this chapter, are successful examples of this type.

FINAL TANKS FOR TRICKLING AND CONTACT FILTERS

Final tanks have been included in connection with trickling filter designs with few exceptions. Their omission is not recommended and they should never be omitted where the effluent discharges into small waterways or shallow lakes or harbors. The liquid portion of the effluent from trickling filters is ordinarily stable, but the sludge in the effluent, if accumulated in banks, will putrefy and cause a nuisance.

Character of Sludge.—Sludge from contact and trickling filters during normal operation is sometimes brownish, often black,

is not particularly offensive as regards odor when recently discharged, settles readily and can be dried usually without nuisance on drying beds. At periods of unloading of the filters worms and grubs are discharged, sometimes in enormous numbers, with the sludge. As removed from settling tanks the sludge contains from 92 to 95 per cent water.

The nitrogen content is relatively higher than for sludge from preliminary tanks. During the war the recovery of fertilizing elements of trickling filter slurry was proposed by Fuller at Indianapolis; but the later drop in fertilizer prices caused that proposition to be abandoned. The disposal of this sludge has therefore followed the practice for the sludge from preliminary settling tanks, either separately or mixed with the preliminary sludge.

Quantity of Sludge.—On an average there is as much, or more, suspended matter in the effluent from trickling filters as there is in the influent, and ordinarily about 65 per cent of this will be collected in well designed settling tanks. At Reading the sludge removed from shallow settling tanks, with an average detention period of 2.6 hours, amounted to about 2 cubic yards per million gallons with a water content of 95 per cent.

Ordinarily in design the quantity of sludge to be deposited in final tanks is of less importance than means for its removal at frequent intervals to prevent putrefaction. Where humus sludge is pumped to preliminary digestion tanks, removal is usually made daily and provision for storage is not a factor. Where sludge is delivered to drying beds, provision should be made for sufficient sludge storage so that withdrawals will allow reasonable operation of sludge drying beds. With normal domestic sewage well designed settling tanks should remove on an average of from 1½ to 4 cubic yards of sludge per million gallons of filter effluent, but sometimes much more where the sewage contains much suspended matter. Sludge storage space should be allowed for a period of about 1 week, depending on arrangements for withdrawing and drying and other local requirements. The actual discharge of suspended matter to settling tanks will vary greatly, but during times of disgorging, tanks may be cleaned more often. At times of low suspended solids somewhat longer periods of detention in the settling tanks will have no ill effect. In some cases it may be advisable to return sludge to Imhoff or primary tanks for digestion.

Arrangement and Size.—Final settling tanks should be divided into several small units rather than a few large ones, so that the cutting out of any unit for repairs or cleaning will not overload the remainder. Such an arrangement is also helpful when treatment works designed for future needs are started in operation, as the flow is usually much smaller at that time than the plant is designed for and the use of large units would allow putrefaction of settled solids.

In design of final tanks for small installations, particular care must be taken promptly to check inlet velocities, otherwise increased velocity of flow following intermittent discharges of the trickling filter will stir up solids previously deposited in the basin and carry them over the effluent weir.

Rectangular horizontal flow tanks need not be greater in depth than is necessary to prevent the stirring up of deposited suspended matters by the velocity of flow of the sewage. Ordinarily 6 feet should be satisfactory. Vertical or hopper-bottomed tanks are sometimes circular in form and have a depth of at least 15 feet.

The construction of final tanks is similar to that already described for preliminary tanks and will not be gone into in detail here.

Floor Slopes.—Horizontal flow shallow tanks naturally tend toward flat floor slopes. Hoover at Columbus estimates that 1 in 125 is sufficient to drain the bulk of the sludge to the outlets. A slope of at least 1 in 50 is preferable. On the other hand, greater slopes tend toward greater expense, and unless hopper bottoms are formed in floors, it is questionable if slopes can be obtained which at all times will automatically discharge the sludge to outlets. It is generally necessary to scrape or flush the sludge to outlets.

With vertical or hopper-bottomed tanks the slope of bottoms should be if possible 1.5 vertical to 1 horizontal to prevent deposits; 1.2 vertical to 1 horizontal has been often used, but usually where water jets were available to loosen the sludge.

Dorr thickeners have been used at Decatur and Elgin, Ill. as final settling tanks following trickling filters and have been proposed elsewhere for similar use.

TANKS FOR ACTIVATED SLUDGE

Where the activated sludge process is used for purifying sewage, final tanks are utilized for other purposes than with other types

of treatment works. These tanks are further discussed in Chapter XXXVIII, Activated Sludge Plants. Such tanks require suitable methods for collecting suspended solids and the removal of these solids for use in further purification processes as well as for disposal. The sludge settles more readily than that from trickling filters, but it is much greater in quantity than from other treatment methods, often as much as 40 cubic yards per million gallons of sewage treated. It is very flocculent and the percentage of water ranges from 98 to 99.5 per cent. Horizontal flow tanks have proved to be much more efficient than vertical flow tanks with this kind of sludge. The maximum allowable velocity in horizontal flow tanks is about 2½ feet per minute while with vertical flow tanks it is necessary to reduce the velocity to about 8 feet per hour.

Capacity.—Activated sludge plants were first designed with a settling tank capacity equal to about 30 minutes of average sewage flow. Recommendations for Packingtown wastes include settling tanks of a capacity of from 30 to 60 minutes' detention period. These short periods have been found to be insufficient in actual practice and have been increased in recent installations to about 2 hours based on the average daily flow and, if inflow rates are unusually variable, to even greater capacity. At Houston, Tex., settling tanks were constructed in 1917, with 2 hours' capacity at the average rate. Detention periods in English plants are longer.

At Milwaukee, Copeland found that there was considerable difference in required settling tank capacity depending on the condition of the sludge with respect to its partial or complete activation. With a 3-hour aeration period sludge equal to as much as 8 per cent per day of the liquid volume of the aeration tanks was accumulated, while with 6 hours' aeration there was only about 2 per cent. Well aerated sludge also settled more quickly than when partially aerated. As the latter contained more flocculent matter, it was more bulky and required greater sludge storage capacity.

Efficiency.—As a general rule settling tanks having a detention period of 2 hours at average rates of flow, and with the sludge well activated, will remove at least 90 per cent of total suspended solids where velocities are not greater than those stated above. Milwaukee experiments would indicate that equally important with velocity and depth are the area at the bottom of the tank

and the rapid removal of the collected suspended matters, it being found that there must be ample space at the bottom so that displaced water ascending will not carry with it descending particles of sludge.

Sludge Removal.—Sludge should be removed from settling tanks practically as rapidly as it is collected. An accumulation of sludge around the discharge pipe may cause the formation of a funnel-shaped opening through the sludge around the pipe and putrefaction of sludge adjacent to the walls. Sludge once deposited may be raised again by gas evolution, by disturbances due to increased flows through the tanks and by increased velocities due to the decrease in capacity, caused by deposits.

ODORS

If sludge from final tanks is removed before putrefaction is established, there will be no odors from them. If storage is continued until putrefaction has started in any type of final tank, there will be a production of odors and with activated sludge tanks much more quickly than with final tanks receiving trickling filter effluents, because of the character of the sludge.

REPRESENTATIVE FINAL SETTLING TANKS

Columbus, Ohio.[1]—The final settling tanks or basins at Columbus, put into service in 1908 for clarifying the effluent of trickling filters, are examples of the shallow flat-bottomed type. There are two basins, each containing about 2 million gallons, designed to provide at normal flow a period of detention of nearly 5 hours when both are in service. The basins are from 4 to 4½ feet deep. The inlets consist of fifteen 21-inch pipes distributed along one side of each basin; the outlet is a circular weir, 19 feet in diameter, located in one corner of the basin. The sludge is pumped to the river at times of high water.

Birmingham, England.[2]—The final settling tanks at Birmingham following the bacteria beds are 35 feet square in plan. They have a total depth of about 25 feet below the sewage level. For a depth of 7 feet the walls are vertical. The bottom is hopper shaped. These tanks are of a type having a combination of upward and horizontal flow. Trickling filter effluent enters each tank at the center and is discharged downward at a velocity of 1

[1] Trans. Am. Soc. C. E., 1910, Vol. 67, p. 302.

[2] Proceedings, Institution of Civil Engineers, 1909–10.

or 2 feet per second from a pipe ending about 12 feet below the surface. The tank effluent is discharged over a weir extending

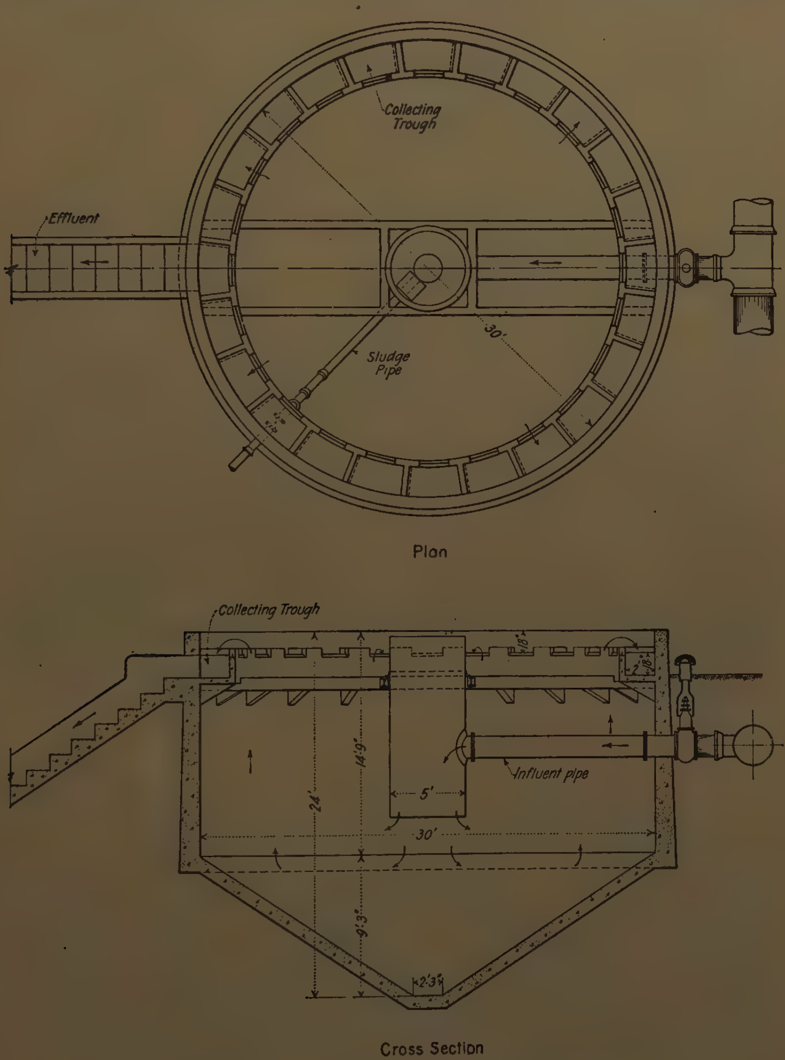


FIG. 56.—Final settling tank, Fitchburg, Mass.

the full length of all four sides of the tank. Sludge is removed by hydrostatic pressure through a pipe extending from a sump at the bottom. With an average period of retention of about 2½

hours and a vertical velocity of $^{9}/_{100}$ to $^{12}/_{100}$ inch per second the removal of suspended matters has been practically complete. For several years the tanks removed more suspended matter than was present in the sewage entering the filters. This was attributed by Watson to colloids intercepted by the filters and later washed out.

Fitchburg, Mass.—The four final settling tanks used to treat trickling filter effluent at Fitchburg are examples of tanks having a combined vertical and radial flow. Each tank is 30 feet in diameter and 22.5 feet deep below the sewage level, as shown in

Fig. 57.—Final settling tanks, Worcester, Mass.

Fig. 56. The side walls are vertical for a depth of about 13 feet below the sewage level and the bottom is conical. The filter effluent is discharged downward at the middle of the tank through a 60-inch pipe terminating at a depth of about 10.5 feet below the sewage level. The tank effluent passes out over 24 weirs, each about 2 feet long, arranged uniformly along the periphery of the tank. The sludge is pumped to the preliminary Imhoff tanks. The average volume during a 10-year period has been about 300 gallons per million gallons of sewage, with an average water content of about 93.4 per cent. The effluent usually contains about 25 parts per million suspended solids.

Worcester, Mass.[1]—Figure 57 shows a view of the four final settling tanks, each 60 by 120 feet and 15 feet deep, hav-

[1] Engineering News-Record, Vol. 91, p. 832, November 22, 1923.

ing a detention period of $1\frac{1}{2}$ hours. These tanks have hopper bottoms with relatively flat slopes quite similar in design to the bottom of the local Imhoff tanks.

Final Tanks for Activated Sludge.—Examples of final tanks for activated sludge plants are given in Chapter XXXVIII.

CHAPTER XXXVII

ACTIVATED SLUDGE PROCESS

SYNOPSIS

1. Description.—Sludge is activated by aerating sewage for a sufficient time to permit the solid particles to become coated and impregnated with growths of oxidizing bacteria and other organisms. Such activated sludge, with gelatinous surfaces and oxidizing properties of a biochemical nature, is mixed with the sewage to be treated for 3 or more hours in an aerating tank, well supplied with atmospheric oxygen. Here suspended and colloidal matters of the sewage become attached to the activated sludge particles and dissolved organic matter is oxidized by the bacteria and their enzymes. The sludge is then separated by sedimentation, leaving a clear and well purified effluent. A portion of the sludge is returned to the inlet of the aeration tank and the excess is dried for use as a fertilizer, digested or otherwise disposed of as described in Chapter XXXIX.

2. Process.—The process is biochemical and differs from the filtration processes described in earlier chapters only in that in filters the unpurified sewage moves over suitable films attached to particles of filter material, while in this process sludge particles with similar films are circulated through the sewage to be treated.

3. Extent of Use.—Working plants were put in service at Worcester, England, in 1916 and at San Marcos and Houston, Tex., in 1917. At Milwaukee a 1-million gallon demonstration plant was built in 1915. Since the war this process has been recommended in various countries for a majority of sizable projects where substantially complete purification is needed.

Large plants have been built at Milwaukee, Indianapolis and Chicago. In Europe there are over 40 built or building with an aggregate capacity of about 50 million U. S. gallons daily, dry weather flow. There are also about 20 plants of this type in Canada.

4. Efficiency.—This process can remove over 90 per cent of the suspended matter and saprophytic bacteria, 90 per cent of

the biochemical oxygen demand and 95 to 98 per cent of the pathogenic bacteria of raw sewage unmixed with excessive quantities of industrial wastes. Thus it is on a par with trickling filters.

5. Advantages.—This process produces a thoroughly satisfactory effluent. It operates with complete freedom from odors and flies, on a minimum area of land and, omitting sludge utilization, at less investment cost than for any other process giving comparable results for large projects. It is adapted, due to the final sludge containing non-settleable materials, to the utilization of byproducts, either by increasing the volume of gas from sludge digestion or by producing a sludge with a higher nitrogen content.

6. Disadvantages.—In earlier years this process was rated as having a relatively high operating cost and so sensitive as to require trained supervision, especially with intermittent discharges of industrial wastes. Now, however, it is better understood and current experiences point to a lessening both of operating cost and of needed watchfulness over ordinarily trained operators who will faithfully carry out essential instructions. Complications may arise, however, where industrial wastes exceed certain limits.

7. Present Status.—In cases where a high degree of purification is sought, this process is entitled to major consideration for sizable new projects. This statement should not be construed to eliminate filters for small projects or for cases where suitably isolated areas permit trickling filters to be appropriately used. No doubt there are many cases where careful investigation is required to decide wisely between this process and filters, both for new projects and the extension of existing trickling filter plants. Local cost of power is an important item.

HISTORICAL DEVELOPMENT

Attempts were made fully 30 years ago to purify sewage by means of aeration, but mostly in connection with filters of one type or another. In 1910, however, Black and Phelps experimented with the aeration of sewage in tanks and showed that a substantial reduction in putrescibility could be obtained. Experiments were conducted by Clark and Gage at the Lawrence Experiment Station, on aeration of sewage, first in bottles and later in tanks filled with roofing slates spaced about 1 inch apart. These tanks were filled with sewage and aerated for several hours by means of perforated pipes at the bottom and the sewage then

drawn off. After successive doses of sewage had been treated in this way, it was found that the slates rapidly became coated with a brownish-gray gelatinous deposit, closely resembling the sediment discharged from trickling filters. This deposit appeared to collect a large part of both the suspended and colloidal matters from the sewage so that remarkable clarification was obtained, from 77 to 90 per cent removal of total and organic suspended matter being secured. Nitrification was also obtained in certain tests. Other tests were made without the slates.

The experiments of Lawrence were shown to Fowler of Manchester. England, when on a visit to the United States in December, 1912. On his return to Manchester he suggested in 1913 to Ardern and Lockett that they should repeat the Lawrence work. They made a series of researches into the efficiency of aeration of sewage. From other experiments it was concluded that the presence of a particular form of iron bacterium M7 was essential to produce the sediment instrumental in purifying sewage. Later experiments, however, conducted at Manchester and by several investigators in America, proved that the development of the sludge was dependent upon the growth of living organisms belonging to a great many species.

Ardern and Lockett found, by continuing the process of aerating the sewage in their experimental tanks for many weeks, that protein compounds could be broken down, and the nitrogen set free converted from ammonia into nitrites and into nitrates.

They aerated sewage in a tank until nitrification was obtained, then allowed the sludge to settle and decanted off the clarified supernatant sewage. By repeating this procedure with successive doses of fresh sewage, they gradually built up an accumulation of material which they called "activated sludge." This was the same as the work carried on by Clark at Lawrence.

Comparative experiments were made by Bartow and Mohlman in 1914–15 at the University of Illinois, to determine the importance of the presence of activated sludge in obtaining rapid nitrification. Their findings are shown in Fig. 58. They demonstrated that it was not necessary to nitrify completely the initial charges of sewage, but that sludge could be built up with a 6 or 12-hour aeration period which would become as highly activated in 2 weeks as that obtained previously in 2 or 3 months.

Hatton at Milwaukee, Frank at Baltimore and others modified the procedure by running sewage through tanks continuously,

the activated sludge being mixed with the sewage as it entered the tanks. After aeration, the combined liquors were run into separating tanks where the suspended matters settled out. This sludge, drawn off continuously, was fed back into the raw sewage. By adopting a similar procedure the modern types of continuous flow activated sludge plants are enabled to treat sewage at much less cost than tanks installed upon the fill-and-draw principle.

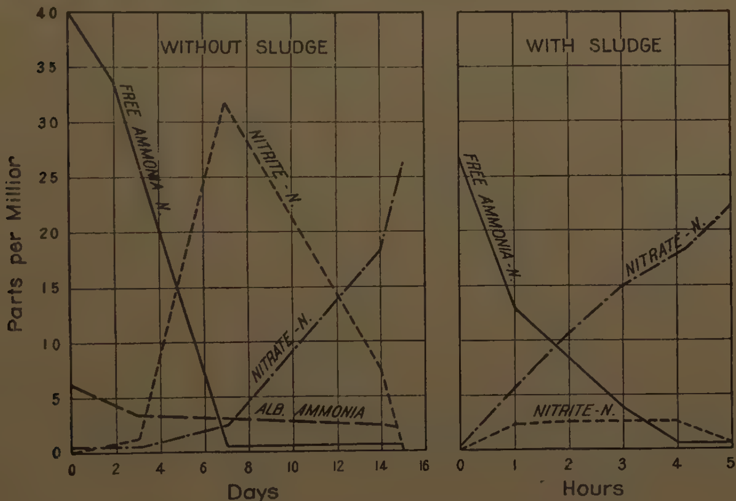


FIG. 58.—Effect of aeration with and without sludge.

CHARACTERISTICS OF ACTIVATED SLUDGE

Sludge particles become coated and impregnated with suitable activated material when sewage is aerated from a week to a month, depending upon temperature and other conditions. In order that oxidizing bacteria may grow and produce their enzymes, it is necessary that some atmospheric oxygen be present at all times and places throughout the sewage to be activated. In practice there are usually some accumulations of sewage solids in which deaeration occurs so that oxygen is absent, with the result that septicization and reducing bacteria may occur. Such a condition is promoted by the breaking apart of sewage solids, due to the pressure of gas formed within them, and the exposure of fresh surfaces on which there are no oxidizing bacteria. Then there are released from the interior of the sludge particles types of bacteria and enzymes capable of reducing or septicizing rather

than oxidizing action (see Chapter VI). Hence there is more or less antagonism between the two groups of biochemical activities, and in practice the activated sludge process is effective only when a great preponderance of the sludge particles are coated or activated with films produced by oxidizing bacteria.

FUNDAMENTAL PRINCIPLES OF THE PROCESS

The activated sludge method of sewage purification depends upon the decomposition and oxidation of the organic matter by living organisms and their enzymes. The most active organisms in this process are the bacteria. They form flocculent jelly-like masses which have a sticky coating. As these masses of zoöglea sweep backward and forward through the sewage in the tanks devoted to aeration and mixing, some organic compounds are absorbed into their structure and others are attached to them, and soluble compounds are broken down into simpler forms (see Chapter VI).

After the sludge has been brought to its normal condition of activation, the time required for it to clarify the sewage varies from 2 to 10 hours, depending upon the strength of the sewage, nature of the compounds which it contains, volume and method of application of air and degree of purification.

Preliminary Treatment.—It is helpful to remove coarse floating matters and also material which would settle on the floor of the aerating tanks. Fine screens are used at Milwaukee and Indianapolis, while sedimentation is employed at nearly all English and German plants and in the design for the Chicago North Side plant. The air consumption may be decreased appreciably by the removal of these coarse solids.

Aerating Tanks.—After building up an adequate quantity of activated sludge, it is necessary to mix this thoroughly with the sewage to be treated. This is done in aerating tanks holding say from 3 to 20 hours flow of sewage, together with 10 to 20 per cent of activated sludge, measured by volume after settling for 1 hour, or 0.2 to 0.4 per cent of dry suspended solids by weight. In the aerating tank three conditions should be provided, viz:

(*A*) Some oxygen in all places at all times to promote the growth of oxidizing bacteria.

(*B*) Mechanical mixing of activated sludge with the sewage to be treated so that the colloidal and suspended matters will be

collected on the gelatinous surfaces and biochemical changes may proceed.

(*C*) Avoidance of accumulations, especially on the floor of the tank, of suspended solids which facilitate the development of anaerobic or septic conditions, antagonistic to the desired oxidizing bacteria, and capable of deactivating much or all of the sludge. This is called "bulking" as explained below.

Types.—In many plants, compressed air, admitted at the bottom of the aerating tanks, is employed both to agitate the mixture of activated sludge and sewage as well as to supply the oxygen needed for the process. There are a number of installations, however, particularly in England, where the liquid is agitated by paddle wheels or other mechanical means, and the necessary oxygen is derived from surface contact of the moving liquid with the air (see Chapter XXXVIII).

Size.—The required size of the tank depends on the strength of the sewage, its temperature, per cent of activated sludge in the tank, thoroughness of mixing, effect of trade wastes and quality of effluent sought. Table 65 shows effect of varying periods of aeration with Milwaukee sewage.

Table 65.—Purification of Sewage Compared with Period of Aeration

Aeration, hours	0	1	2	3	4	5
Cu. ft. of air per minute	0	160.00	160.00	160.00	160.00	160.00
Cu. ft. of air per gallon	0	0.67	1.32	1.98	2.64	3.31
Appearance of settled liquor	Turbid	Clear	Clear	Clear	Clear	Clear
Stability, hours	0	2.00	33.00	120+	120+	120+
Bacteria removed, per cent	0	52.00	81+	92+	95+	98+
Free ammonia, parts per million	22.00	17.00	15.00	11.00	7.00	5.00
Nitrites, parts per million	0.08	0.00	0.95	1.75	2.20	2.50
Nitrates, parts per million	0.08	0.04	0.70	2.80	5.60	8.20
Dissolved oxygen, parts per million	0.00	0.30	1.90	4.30	5.90	6.70

Settling Tanks.—From the aerating tanks the sewage is passed through final settling tanks to separate from the liquid the flocculent activated sludge, which is dispersed through the treated sewage (see Chapter XXXVI).

Return of Sludge.—From the settling tank sufficient of the 98 to 99 per cent sludge should be returned to the raw sewage entering the inlet of the aerating tanks to insure the desired volume of activated sludge in it.

Excess Sludge.—The excess sludge from the settling tanks is disposed of either by delivering it to the preliminary settling tanks, or to drying beds, or to lagoons or to a plant for making it into a fertilizer, as explained in Chapter XXXIX.

Bulking of Sludge.—Occasionally aerating tanks have failed to function and the volume of sludge has become unusually great. This is called bulking. Various factors may influence it but the main item seems to be that the sludge has lost its activation on an oxidizing basis. That is, anaerobic or septic conditions predominate; hydrolysis sets in and the sludge swells and no longer shows its adsorptive, oxidizing properties. It is really in the initial stages of septicization (see Chapters VI and XXI). Illustrative of conditions which cause bulking it may be pointed out that (1) the floor of the aerating tank may have become fouled with decomposing deposits, (2) the aerating period may be too short to provide a good sludge as it goes to the settling tank, (3) the sewage to be treated may become abnormal through the presence of industrial wastes or of septic conditions with their anaerobic enzymes such as occur during very dry weather when sewage solids become stranded in the sewers and there decompose, and (4) the adsorptive oxidizing properties of the activated sludge, to be mixed with the sewage to be treated, may have become impaired by too long detention in the final settling tank, or entirely overtaxed in the aerating tank, due to excessive quantities of solids in the untreated sewage just after storms. Protozoa and other forms of microorganisms are associated with bulking, but these may be the result rather than the cause of this particular condition.

Reaeration of Sludge.—Practice varies as to providing facilities for reaerating sludge removed from the settling tanks, particularly that which is returned to the inlet of the aerating tanks. Many of the large recent designs omit this feature on the basis that it is unnecessary and that it is safer to make the aerating tanks large enough so that the sludge is well conditioned in the presence of a large excess of well oxygenated liquid. The deoxygenating power of the concentrated sludge is so great that it is difficult to apply enough air to keep it aerobic. When mixed with sewage, aerobic conditions may be maintained more easily. Notwithstanding that there are some drawbacks to reaerating sludge, especially if undiluted with tank effluent, it is considered by some to be worth while for emergency use. At plants where

only partial purification is sought as a preparation for filtration it is thought necessary, as at Birmingham, whereas at Decatur it has not been found necessary.

Septic Sewage.—It is not desirable to treat sewage in which septicization has become established, although experience at Sheffield shows that a well settled effluent from a tank in which there is some septic action is tractable. However, during very dry periods in England when the flow is very concentrated and solids are stranded and partially septicized within the sewer, the process is interfered with. Apparently this is due to an excessive accumulation of enzymes of anaerobic bacteria which prevent functioning of the oxidizing bacteria in the aerating tank. It can be overcome by dilution of the influent with tank effluent.

Industrial Waste.—Most wastes add to the strength of sewage and have a tendency to increase the loading of a plant. But they do not interfere with the process unless through germicidal action they arrest bacterial growth, as in the case of strong acids, alkalies, etc. Paint wastes, containing copper, arsenic or other mineral poisons are also detrimental. Phenol wastes can ordinarily be handled successfully if such liquors from gas works, creosoting plants, etc. do not exceed about 3 per cent of the sewage flow (see Appendix B). Tar or mineral oil is very objectionable, both from the standpoint of purification and sludge disposal. Such inert material is not oxidized and covers the surface of aeration tanks; it destroys the coagulative properties of the sludge, and greatly increases the difficulties of filtration. Oily or tarry wastes have become very objectionable at the Des Plaines, Indianapolis and Milwaukee activated sludge plants.

Supplementary Treatment.—When normally installed and operated, the activated sludge process requires no supplementary treatment. At Birmingham, England, as later described in this chapter, the activated sludge treatment is carried on in a relatively small aerating tank, to remove a part only of the organic matter. This is done as a preliminary treatment for trickling filters and enables them to operate at about double the normal rate. While helpful for local conditions there, it does not follow that the step would be wise for a new project.

INFLUENCE OF PRELIMINARY TREATMENT

Sedimentation is a more effective method of preliminary treatment than fine screening. Due to more thorough removal of the

organic matter requiring oxidation, sedimentation may reduce the amount of air required for the activating process 15 or 20 per cent under that required in the case of treatment by fine screens. Sedimentation helps by removing heavy matters which would tend to settle in the aeration tanks and interfere with aeration and circulation. Sedimentation also removes, at least partially, such solids as may have become septicized before reaching the tank and which, on that account, would be more difficult to treat by aeration. In cases where solids from trade wastes, of such nature as to cause sterilization of the sewage, are brought to the plant, sedimentation is also of material aid in preventing interruption of activation. The period of detention of the sewage in the sedimentation tanks should, however, be as short as consistent with a fair removal of solids, so that the sewage may be kept as fresh as possible, and thus more readily oxidizable.

Another advantage of sedimentation tanks over screens is that oil and floating matters are more readily removed with the aid of good scum boards.

SIGNIFICANCE OF NITRIFICATION

The bulking of sludge is not much of a factor in American practice with the activated sludge process. While American plants use somewhat more air per gallon of sewage treated than do English plants, American sewage is much more dilute. The amount of air used in American plants per capita of population connected or per unit of organic matter in the sewage is therefore much greater. The oxygen contained in the diluting water is also of much value, both in keeping the sewage fresh and in aiding in the activation of the sludge. It is therefore not difficult and is customary in American plants to carry nitrification farther than in English plants, thus providing an additional margin of safety. The amount of nitrification may be increased or diminished, depending upon the purity of effluent desired, by increasing or reducing the length of the aeration period and the amount of aeration provided.

It has been found at the Des Plaines plant that the filterability of the sludge varies directly with the amount of nitrification. When nitrates are allowed to disappear, it is much more difficult to filter the activated sludge. Insufficient or minimum air volumes invariably result in a sludge that filters with difficulty.

As a rule nitrification of the effluent is characteristic of American plants but not of English plants, except on Sundays and holidays.

On the other hand, sedimentation as a preliminary treatment is almost universal in England but quite rare in America.

ACTIVATED SLUDGE PROCESS FOLLOWED BY BACTERIA BEDS

At Birmingham,[1] as a result of careful investigation, use is made of the activated sludge process as a preliminary treatment

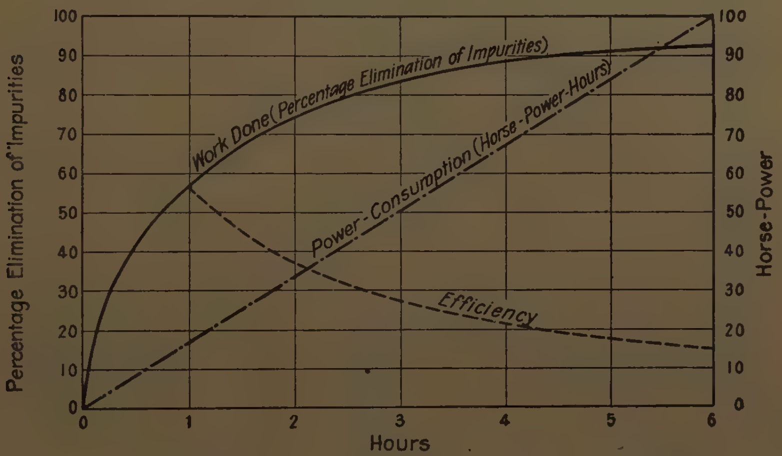


FIG. 59.—Relation of power consumption to results accomplished.

for the sewage applied to bacteria beds (trickling filters). It has been found that about 60 per cent of the fine suspended and colloidal matter which tends to clog filters can be removed with about 1 hour's aeration, so that the effluent can be efficiently treated on the trickling filters at more than double the rates otherwise possible. In order to obtain effective clarification of the sewage in an hour, it is planned to reaerate thoroughly the returned activated sludge so as to maintain it in effective condition. One strong advantage claimed for this plan is that the possibility of objectionable odors rising from the filters is very much reduced if not entirely eliminated. Furthermore, it

[1] "The Works of the Birmingham, Tame and Rea Drainage District Board," by J. D. Watson, Surveyor, Vol. 64, p. 67, July 27, 1923. Also later edition of above by H. C. Whitehead, 1926. "Partial Purification of Sewage by Activated Sludge," by H. C. Whitehead, Surveyor, Vol. 68, p. 449, Nov. 20, 1925.

makes possible a more effective utilization of the very large investment in filters already made at Birmingham.

The relation of results accomplished to power consumption at different stages of the process, according to the Birmingham experiments, is well shown in Fig. 59.

It was determined at Birmingham that there was no object in carrying forward to the activated sludge plant more suspended matter than absolutely essential to produce and maintain a satisfactory amount of activated sludge, and experiments there show that 80 parts per million colloidal sludge are sufficient to produce from 2 to 5 per cent by volume of activated sludge in the aerating tank.

EXTENT OF USE

Several large plants for treating sewage by activated sludge are being constructed or have been put into operation in America. Chicago has partially built a plant to have a capacity of 175 million gallons of sewage per day. At Milwaukee an activated sludge plant is now in service which has a capacity of 85 million gallons of sewage per day. The sewage of Indianapolis is treated by an activated sludge plant which has a capacity of 50 million gallons of sewage per day. Houston, Tex., has been operating two plants for several years that have a combined capacity of 12 million gallons of sewage per day. Smaller plants have been operating for several years at Pasadena, Gastonia, San Marcos and at the Des Plaines and Calumet sewage works at Chicago. More than 20 plants are now in active operation in Canada and there are more than 30 plants in actual operation in England, Germany, Holland and France.

APPLICABILITY

The activated sludge process has been employed successfully to treat sewages all over the world. It is applicable for the purification of any normal sewage.

The results obtained in the treatment of sewage by the activated sludge process are truly remarkable, particularly the high degree of purification which can readily be secured. When the treatment is properly carried out, the suspended solids and colloids are removed so completely that an almost perfectly clear and sparkling effluent results. A very large percentage of the

bacteria is likewise mechanically swept out with the fine suspended matter, in a manner similar to the coagulation of turbid waters.

Colors and odors are generally substantially removed as a result of oxidation or absorption by the activated sludge, although certain dyes and tar products may be very resistant and may, in fact, exercise an inhibiting effect on the process itself.

FLEXIBILITY WITH RESPECT TO WET WEATHER FLOW

During wet weather the activated sludge process responds readily to the increase in rate of sewage flow from combined sewers, especially where settling tanks are used for preliminary treatment. While the volume of sewage to be treated is much greater during storms, the proportionate amount of organic matter to be oxidized per unit of volume is much less after the "first flush" is over. Furthermore, the oxygen contained in the diluting water is a helpful factor. It is essential, however, that the final settling tanks be properly proportioned for the maximum rates of flow, and that ample facilities be provided for removing as required unusual volumes of activated sludge from them.

In England greater flexibility is claimed by some for the activated sludge method than for trickling filters, but in America there are no comparable data on this point. Until more operating experiences are obtained on a large scale it is not wise to be dogmatic or too specific in making comparisons.

CHAPTER XXXVIII

ACTIVATED SLUDGE PLANTS

SYNOPSIS

1. Description.—As constructed in practice, an activated sludge plant consists primarily of aeration tanks in which sewage is agitated and aerated in contact with 10 to 20 per cent of sludge already activated; and final settling or separating tanks by which the sludge in the effluent from the aeration tanks is separated from the clear liquor to be in part returned to the aeration tanks and in part removed for disposal. Reaeration tanks for again aerating the returned sludge are sometimes provided. Preliminary treatment of the sewage by screening or sedimentation is needed, although not always provided.

2. Aeration Tanks.—These tanks are essentially narrow rectangular channels, frequently several hundred feet long and 15 feet or less in depth, in which the mixture of sewage and activated sludge is retained for 4 or more hours. Aeration is generally accomplished in this country by discharging compressed air up through the liquid; but frequently in England by revolving paddles or other mechanical means. A combination of both methods is sometimes employed. Since the tank bottoms must be kept free from sludge, which might decompose, the bottoms are frequently built with ridges and furrows, with air diffusers in the furrows. Tanks with flat bottoms generally have air diffusers set along one side, which promote a spiral motion of the liquid, keeping the bottom clean as well as providing good mixing.

3. Final Settling Tanks.—For separating the sludge from the mixed liquor coming from the aeration tanks, settling tanks are used. These tanks must be designed for low velocities and with careful arrangement of inlets and outlets, in order to allow the light, flocculent sludge to settle. To permit prompt and thorough removal of the sludge, separating tanks are constructed either with very steep hopper bottoms, or with relatively flat bottoms cleaned by mechanical devices, such as Dorr thickeners (see Chapter XXXVI).

PRELIMINARY TREATMENT

In practically all cases it is advisable to provide preliminary treatment of some sort in advance of the aeration units, particularly where these are equipped with porous plates for air diffusion. With combined sewers, coarse racks and grit chambers are needed to remove large floating material or heavy suspended matter respectively, which would be liable to collect in tanks and clog pipes and conduits. Fine screens or preliminary settling tanks are desirable to remove the larger part of the coarser suspended matter, as it is not readily handled by the activated sludge process and it puts a needless burden on the plant. In most cases, the preliminary removal of a substantial part of the suspended matter in settling tanks will permit appreciable economies in the use of air.

AERATION TANKS

Proportions.—There is considerable diversity in practice as regards the depth of aeration tanks. Many of the English tanks have been reconstructed from existing settling tanks and are comparatively shallow. The Sheffield tanks, for example, are only 4 feet 5 inches deep, having been constructed in old contact beds, but they are equipped with mechanical agitation. The new plant at Reading, England, has aeration tanks 22 feet deep. In this country the general practice seems to be to make aeration tanks about 15 feet deep in the larger plants and frequently somewhat less in smaller layouts.

TABLE 66.—CHARACTERISTICS OF VARIOUS AERATION TANKS

	Length of tank, feet	Number of passes	Length of travel, feet	Period of aeration, hours	Per cent of sludge	Rate of travel, feet per minute
Milwaukee	236	2	472	6	20	1.31
Indianapolis	238	4	952	5	20	3.17
Chicago (North Side)	417	1	417	6	20	1.16
Chicago (Calumet)	103½	3	310	4	25	1.29
Houston*	280	2	560	5	20	1.87
Manchester (Withington)*	177	3	530	4.8	15	1.84
Reading, England	180	..	....	9.5	25	
Sheffield, England	265	21	5540	14.0	25†	
Birmingham, England*	.....	..	3360	1.5	...	37.3

* Reaeration. † Assumed.

Tanks are commonly long and narrow and generally baffled so that the sewage traverses the length several times. In Tables 66 and 67 are given the lengths of travel, period of aeration and average rate of travel for a number of plants.

In general the tanks should be designed with reference to the character of sewage, ground area available, power consumption, etc. For example, the tanks at Milwaukee were made 15 feet deep because the area available was small and by using a deep layer of sewage together with the ridge and furrow system of aeration and 1½ cubic feet of air per gallon, the strong Milwaukee sewage can be handled at a rate of 15,000,000 gallons per acre per day. On the other hand the Haworth mechanical paddle type of plant handles less than 3,000,000 gallons per acre per day.

Table 67.—Period of Aeration and Air Consumption

	Type of tank	Depth of tanks, feet	Period of aeration, hours	Air consumption in cubic feet per gallon
Milwaukee	Ridge and furrow	15	6	1.5
Indianapolis	Spiral flow	15	5	0.9
Chicago (North Side)	Spiral flow	15¼	6	1.0
Chicago (Calumet)	Ridge and furrow	14⅓	4	0.8
Chicago (Des Plaines)	Ridge and furrow Spiral flow	2-10 1-15 1-10	4	1.3
Houston	Ridge and furrow	9¾	5	2.25
Manchester (Withington)	Spiral flow	6	4.8	1.1
Sheffield	Mechanical paddle type	4.5	14	

Types of Bottoms.—Some of the earlier English tanks had plain flat bottoms due to the adaptation of existing settling tanks or scrubbing filters to the process. It was found that sludge accumulated between the air diffusers and septicized. Later tanks were constructed with a series of cross-ridges between rows of diffusers, giving a saw-tooth profile to the tank bottom. This

is the type of bottom adopted at Houston, Tex., and also at Milwaukee, as shown in Figs. 60 and 61.

Spiral Flow Tanks.—The most recent designs provide for continuous rows of diffusers along one side of relatively long and narrow tanks with a view to bringing about a spiral motion of the sewage as it progresses slowly through the tank. This design has been adopted in recent English plants as well as at the new Indianapolis plant and the Chicago (North Side) plant now under construction. A view showing the cross-section of the Indianapolis tanks is shown in Fig. 62.

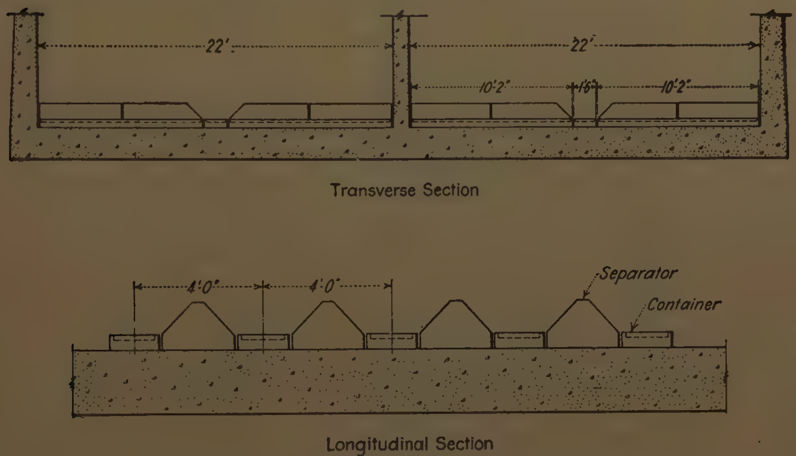


Fig. 60.—Arrangement of Filtros plates, aerating tanks, Milwaukee, Wis.

Elaborate experiments were carried out at Indianapolis on spiral flow in aeration tanks and it was found to be feasible to maintain a spiral flow in tanks as wide as 30 feet and 15 feet in depth, with the application of 0.6 cubic foot of air per gallon and to secure sufficient velocities to keep the tank bottom free from sludge deposits. It was also developed that the upper deflector surfaces placed at an angle of about 45 degrees greatly facilitated the spiral motion. The Indianapolis tanks, as built, however, have a width of 20 feet for each section. Each aeration tank comprises four units 238 feet long, which the sewage traverses successively, and as the pitch of the spiral flow is about 1.75 feet, the total length of surface travel will approximate seven miles. A model showing spiral circulation at Indianapolis is shown in Fig. 63.

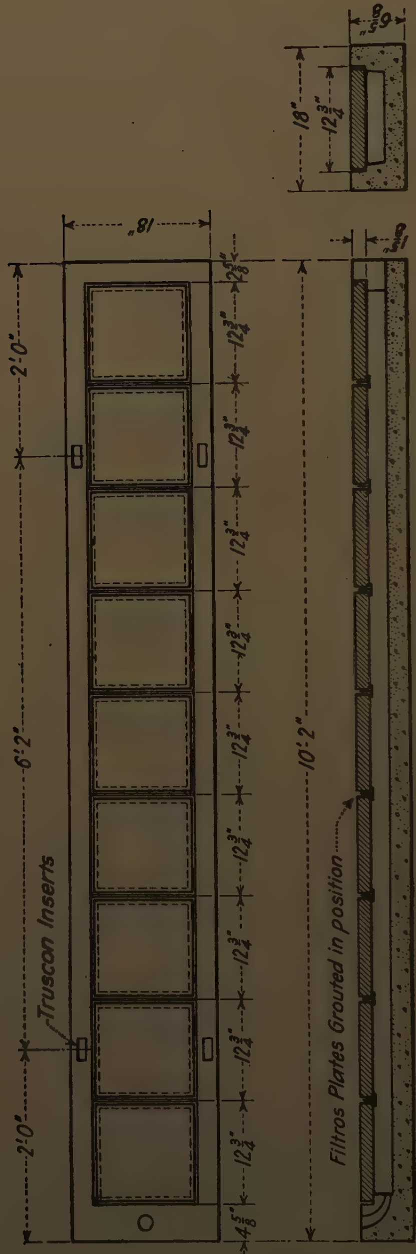


Fig. 61.—Filtros plate container, Milwaukee, Wis.

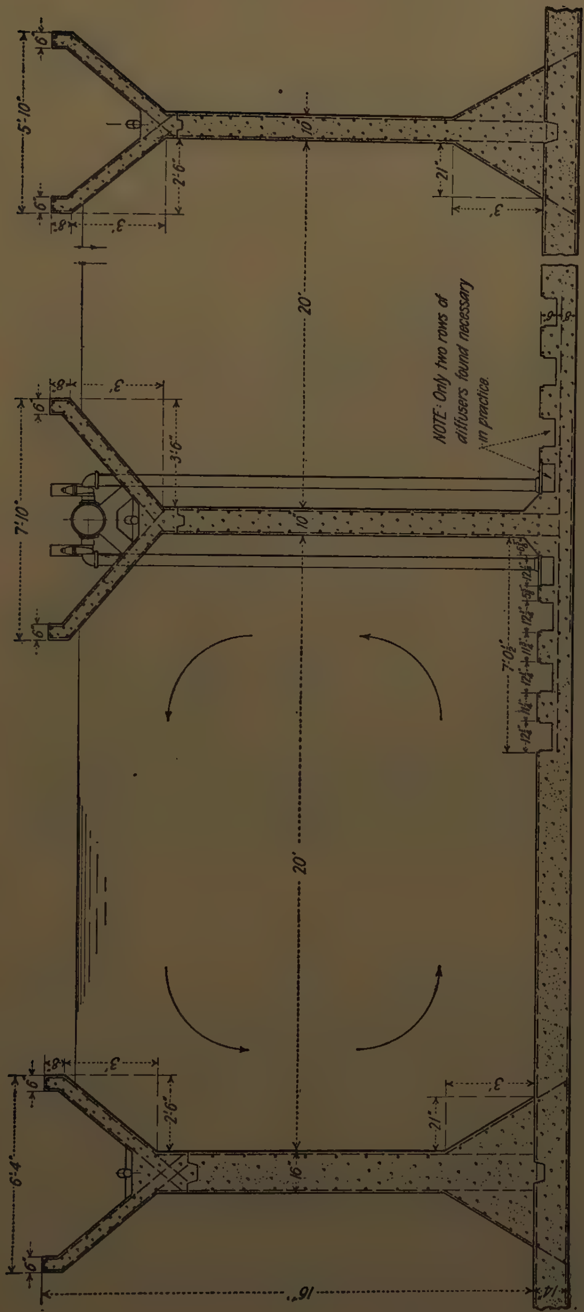


FIG. 62.—Cross-section of Indianapolis aerating tanks.

At the Chicago (North Side) plant angles of 40 degrees with the horizontal are used for the upper deflector surfaces. Likewise tests made at Chicago indicate that a velocity of 1 foot per second across the bottom will keep the sludge in motion.

Air Diffusers.—In practically all American plants, constructed or projected, compressed air has been diffused into the sewage by means of "Filtros" plates, which are manufactured by The General Filtration Company, Rochester, N. Y. Other arrangements, such as perforated pipes, wire mesh and bass wood

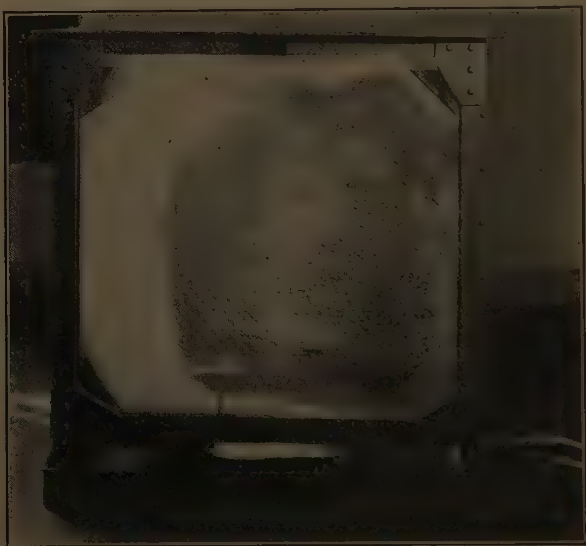


Fig. 63.—Model showing spiral circulation, Indianapolis, Ind.

blocks have been experimented upon, but in no case have they proved as satisfactory or economical.

"Filtros" plates are prepared from carefully graded quartz sand and a silicious binding material baked until hard and are usually 12 inches square and about 1½ inches thick. Seven grades are manufactured, having different frictional resistance to the passage of air, as shown in Table 68. The grades commonly used for activated sludge plants are *R* and *S*, which pass from 10 to 15 cubic feet of air per minute through a dry plate under a head of 2 inches of water.

Similar plates are also manufactured by the Norton Company, Worcester, Mass., from carborundum chips. Diffuser plates

made by Activated Sludge, Ltd., in England by a secret process are said to consist of a coarse concrete pressed into the form of a tile. Canvas bags and porous blocks of concrete have been tried with some degree of success in one or two plants.

TABLE 68.—RESISTANCE OF WET PLATES TO PASSAGE OF AIR

Grade	Average resistance of saturated plate	Resistance of saturated plate when passing per square feet per minute		
		2 cubic feet	4 cubic feet	8 cubic feet
	Inches of water	Inches of water	Inches of water	Inches of water
A	5 to 6	7 to 8	8 to 9	12 to 13
B	5 to 6	7 to 8	8 to 9	12 to 13
C	6 to 7	8 to 9	9 to 10	13 to 14
R	7 to 8	9 to 10	10 to 11	14 to 15
S	8 to 9	10 to 11	11 to 12	15 to 16
E	9 to 10	11 to 12	13 to 14	17 to 18
H	10 to 12	13 to 15	16 to 18	22 to 24

With dry plates the volume of air passing appears to be directly proportional to the pressure, but with the plates water-saturated, this does not seem to hold true, probably because the water in the plate is gradually forced out of the pores. With a fixed volume of air passing, the pressure resistance gradually decreases, or with a fixed pressure the volume passing gradually increases. In other words, the resistance of the water-saturated plate is not constant, hence the latitude in the figures dealing with the ratings of these plates.

In recent American designs, the "Filtros" plates are set in the top of suitable containers which should preferably be made of rich concrete. From 4 to 10 plates are set in a single container, depending upon the size and design of the plant. Cast-iron containers have been used but are very liable to cause clogging of the plates as a result of iron rust. The type of container used at Milwaukee is shown in Fig. 61.

At the Indianapolis plant, the "Filtros" plates are set in individual recesses cast in the concrete floor and connected together, in groups of fifty, by 4-inch vitrified glazed tile

embedded in the floor. The arrangement of the diffusers is well shown in Fig. 62, which also shows the deflectors.

The area of diffusers provided varies materially in different designs as indicated in Table 69, but the smaller area needed with spiral circulation is well illustrated.

TABLE 69.—VARIATIONS IN AREAS OF DIFFUSERS

	Type of aeration tank	Ratio of air diffusers to tank surface, per cent
Indianapolis	Spiral	7.5
Chicago (North Side)	Spiral	10.0
Manchester (Withington)	Spiral	6.0
Milwaukee	Ridge and furrow	25.0
Chicago (Calumet)	Ridge and furrow	19.0
Houston (North Side)	Ridge and furrow	14.0

It is essential with Filtros plate diffusers that the air be perfectly free from dirt, soot, iron rust or other impurities, as such will rapidly collect on the under surface of the diffusers and soon clog them. Likewise, proper drainage of the containers or pockets in which the plates are set appears advisable to prevent moisture condensing or seeping through beneath the plates and causing water binding. The plates are usually set in place with Portland cement mortar, although sulphur and bituminous materials have been tried but with little success.

Air Piping.—Piping for distributing air to the diffusers should be made of reasonably liberal size so that the velocities in general will not exceed 2000 to 3000 feet per minute. All piping should be protected against corrosion so far as feasible, particularly on the inside, as rust will quickly clog the diffusers. Traps are generally provided to remove the condensed moisture from the air mains. Piping should be accessible and so laid out that it can be readily drained in case of flooding, and with ample valves for controlling the supply of air to various sections. At Milwaukee one valve has been found sufficient to control 1000 plates. In English plants, small needle valves are provided on the lines leading to each unit section of diffusers. The total loss of pressure in the distribution piping and diffusers depends on the size of the

plant and the design, but in general should not exceed 1.0 to 1.5 pounds per square inch. A careful investigation of various formulas for air pressure losses in pipe by the engineers of the Chicago Sanitary District[1] developed the fact that the Fritzsche formula was probably best adapted for proportioning air piping, with certain corrections to the coefficients.

Estimates made for the large Chicago North Side plant showed that each 0.1 pound saved in air pressure would result in the saving of about $3000 per year in power cost.

Mechanical Agitation.—English practice shows that it is practicable and economical to carry on the activated sludge process, without artificial aeration with compressed air, by agitating the mixture of sludge and sewage mechanically for a sufficient period so that the necessary oxygen can be absorbed from contact with the air at the surface. Several different types of arrangements have been developed, but the Sheffield system and the Simplex Aeration Process at Bury and Birmingham are perhaps the most noteworthy. These systems are described later.

Volume of Sludge in Aeration Tanks.—A certain amount of activated sludge must be returned to the incoming raw sewage and circulated with it through the aeration tanks. If too little is returned the sewage will not be clarified or stabilized; if too much is kept in circulation it will require a relatively large amount of air to satisfy its oxygen demand and keep it aerobic. A large volume of returned sludge will likewise reduce the time of aeration of the sewage in proportion to its volume. It is therefore important to know what the volume should be. Practice varies widely in this matter, for the volume will vary with the strength of the sewage, condition of the sludge and method of application. As a rule the amount used will range between 5 and 25 per cent by volume of the sewage treated. The volume is usually determined by allowing a measured quantity of the sludge to settle for a definite period, usually 1 hour, in a graduated glass cylinder. A more exact method is to filter a measured volume through some medium such as paper or asbestos and weigh the deposit collected after drying. When this test is used the dry suspended matter should range between 0.2 and 0.4 per cent of the total weight of the mixed liquors. Another quick and convenient method is to separate the suspended solids by using a physician's laboratory

[1] Engineering News-Record, Aug. 2, 1923, p. 178 and Nov. 20, 1924, p. 823.

centrifuge, whirling a measured volume for a definite time and comparing the amount of sediment with the amount of liquor taken.

FINAL SETTLING (SLUDGE SEPARATION) TANKS

Tanks that are to be used for the separation of activated sludge from the aerated liquors ordinarily provide a period of detention of 45 to 90 minutes at maximum rates of flow. The tendency in England and in some plants in the United States is toward longer periods (see Chapter XXXVI). Tanks should be designed not only to permit the particles of sludge to settle, but also to permit removing the solids so that they can be returned to the stream of raw sewage or discharged to the sludge dewatering apparatus. The excess or residual sludge to be disposed of may amount to from 5000 to 15,000 gallons per million gallons of sewage treated.

Velocities.—Many of the particles of activated sludge are so light that very slight currents will prevent them from settling. Therefore the velocity of the entering liquors must be checked and regulated by baffles so that the maximum velocities through the tank will be less than the "settling rate" of the fine particles. This condition can be helped very materially by making long outlet weirs of uniform elevation so as to skim the clarified effluent effectively off the surface. Scum boards are often provided.

To meet this requirement the horizontal velocity should not exceed 2½ feet per minute. At the same time the vertical velocity should not exceed 8 feet per hour.

Attention is called in this connection to the fact that, since the removal of sludge secured is primarily a function of the area rather than of depth or cubical volume of the tank, the tank inlets must be designed so that the velocity of the entering sewage will not create eddies which will stir up deposited sludge or carry the sludge along in suspension.

Removal of Sludge.—Undigested organic matter that will ferment in time is contained within the particles of activated sludge. If the sludge ferments it becomes colloidal and bulky and has a great avidity for oxygen. Such a condition may develop within a few hours. To prevent this, means must be provided to remove the sludge from the settling tanks as it gathers.

Depths of Tanks.—In designing final settling tanks, it is important to allow sufficient depth to provide for fluctuations in the

depth of sludge accumulation or "blanket," which may vary greatly during the day, depending upon the quantity and quality of the sewage. The smaller volume of weak night sewage does not yield as much sludge as the larger volume of stronger day sewage. The sludge accumulation in the settling tanks varies greatly, even though the withdrawal of sludge is substantially uniform as to volume and density. It is therefore necessary to provide ample storage capacity to prevent the sludge from building up to a point where the fine surface sludge blanket commences to pass out in the effluent.

The fluctuations in depth of sludge of different densities in the settling tank during a typical day at Milwaukee, as reported by Eddy, are given in Table 70.

TABLE 70.—FLUCTUATIONS IN DEPTH OF SLUDGE WITH DENSITY

Density* of sludge, percentage of suspended solids	Minimum depth in feet at 6 a. m. ±	Maximum depth in feet at 6 p. m. ±
1	6	12
10	3.5	9.5
90	2	5

* The volume of sludge remaining at the bottom of the test sample after standing quiescent in a glass cylinder, 2¼ inches in diameter and 16 inches high, for ½ hour.

Types of Tanks.—Tanks for the separation of the activated sludge from the mixed liquor fall mainly into two classes. In the majority of the smaller and earlier plants, Dortmund tanks with steep hopper bottoms have been employed. More recently, particularly in the larger layouts, there has been a tendency to install relatively shallow tanks with only slight bottom slopes and to rely on mechanical scrapers like the Dorr thickener for collecting the deposited sludge. Both radial and cross-flow have been employed with both types of tanks.

Hopper-bottomed Tanks.—The most essential requirement of hopper-bottomed tanks is sufficiently steep slopes on the hoppers. Due to the character of activated sludge, slopes of 60 degrees or more from the horizontal are generally necessary to avoid objectionable deposits of sludge, particularly with square tanks as the corners necessarily have less slope than the sides of the hoppers.

Figure 64 shows the Birmingham sludge separating tank which illustrates well the radial flow type of Dortmund tank.

Particular attention is called to the manner of introducing the liquid so as to avoid disturbance of deposited sludge.

Dorr Thickeners.—Dorr thickeners, originally developed for metallurgical work, have in the last few years been applied successfully to sedimentation processes in connection with water purification and sewage treatment, in particular for sludge separation for the activated sludge process. They consist of

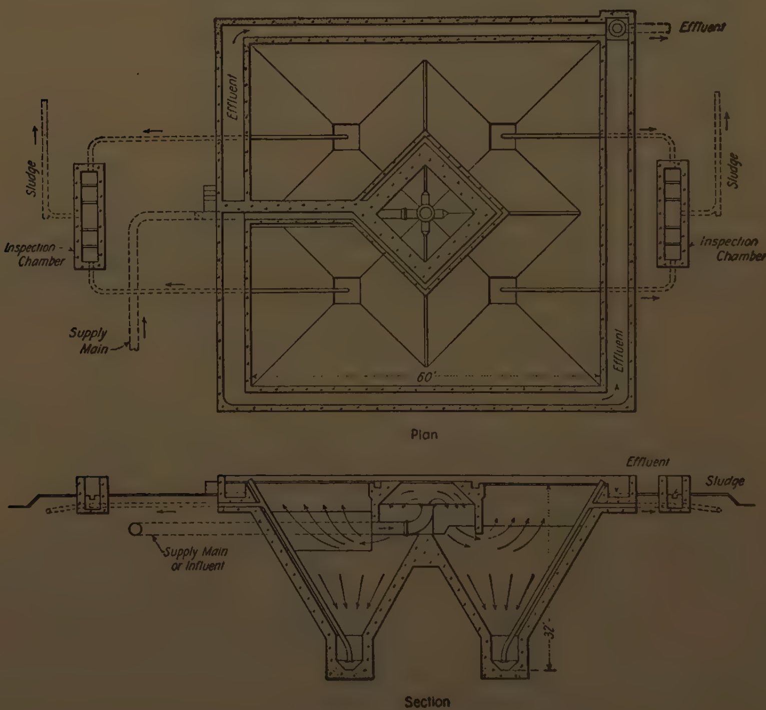


Fig. 64.—Settling tanks, Birmingham, Eng.

square or circular tanks 10 to 15 feet deep, with bottoms sloping to sumps ordinarily at a rate of about 1 inch per foot. A system of inclined scrapers, driven by a central shaft and supported by a truss spanning the tank, revolves slowly and the blades gradually push all deposited materials to a central outlet. Thickeners have been built in various sizes from those of laboratory size up to 200 feet in diameter. Rates of settling have been from 1000 to 1600 gallons per square foot per 24 hours, based on the maximum sewage flow.

SLUDGE RETURNED TO AERATION TANKS

Percentage of Returned Sludge.—For ordinary conditions, the recent tendency is to apply 10 to 20 per cent of returned activated sludge to the sewage entering the aeration tanks, but considerable latitude is found in this regard. In general, no higher percentage of returned sludge should be used than is necessary to effect the degree of purification desired, as the cost of both tanks and air compressing is increased.

At Birmingham, England, where a sedimentation tank effluent is treated and only partial purification is sought, satisfactory results have been obtained with 5 per cent returned sludge.

With industrial wastes and very strong sewages, particularly those containing large amounts of colloidal matter, 40 to 50 per cent of returned sludge may be needed to secure effective results.

Sludge Return.—To return sludge from the separating tanks, air lifts are commonly used in the smaller plants, being simple if not very economical devices. Special designs of reciprocating pumps and automatic, compressed-air, sewage ejectors are also available. In the case of larger plants, centrifugal pumps of suitable design usually prove more economical, flexible and satisfactory.

Attention should be paid to pipes or channels carrying activated sludge to secure velocities which will prevent deposits. In certain cases it will be advisable to install diffusers in channels which will keep the sludge aerated. The same applies particularly to tanks for the storage of excess sludge, for putrefaction will rapidly start if a supply of air is not maintained.

REAERATION OF SLUDGE

There is some difference in practice with regard to reaeration of the activated sludge before returning it to the raw sewage entering the aeration tanks. Reaeration was provided in some of the earlier plants, as for example at Houston (North Side), where the reaeration channels are one-half the capacity of the aeration tanks and at Manchester (Withington) where the reaeration channel has about one-eighth the capacity of the aeration tanks. The more recent tendency in America seems to be to omit reaeration entirely, as at Milwaukee and Chicago, or to provide for a limited amount for emergency use, as at Indianapolis. Reaeration was abandoned at the Des Plaines, Chicago,

treatment works after it had been demonstrated that it effected no economy either in air or in required tank capacity.

In the case of ordinary city sewage, where a well oxidized effluent is desired and a liberal period of aeration is provided, there is probably no necessity or advantage in reaerating the sludge.

In special cases, as at Birmingham, England, where it is simply desired to sweep out a sufficient portion of the suspended and colloidal matters so that the effluent may be applied at higher rates to bacteria beds, it is considered essential to reaerate the activated sludge to maintain it in good condition. However, present experiences at Decatur indicate that even with 2 hours aeration on a very strong sewage and almost septic sludge a marked clarification can be obtained.

With many industrial wastes, or with sewages containing large amounts of these, it will prove economical, if not imperative, to reaerate the returned sludge.

MISCELLANEOUS FEATURES OF DESIGN

Ample meters should be provided for measuring the flow of air, sewage and sludge to various sections of the plant as they materially assist in operating it in the most effective and economical manner. The Venturi tube is generally the most satisfactory type of meter, although meters of the orifice or nozzle type can be used and small notch weirs are simple and accurate, particularly for sludge measurement.

Adequate drains should be installed for unwatering all portions of the works to permit convenient and ready inspection or repairs. In particular, all air piping and containers for diffusers should be thoroughly drained.

It is highly important to provide convenient means for inspecting and sampling the sewage and sludge at suitable points.

Means for securing a proper division and control of the flow of air, water and sewage to the different units should be provided, so that each unit shall do its fair share of work and none be overloaded.

AREA REQUIRED

One of the striking facts about the activated sludge process is the relatively small area required as compared with any other process giving comparable results. With a 6-hour aeration

period and tanks 15 feet deep, or with a 4-hour aeration period and tanks 10 feet deep, the net area occupied by aeration tanks, sludge separating tanks and their connecting channels is only about 0.15 acre per million gallons average sewage flow treated.

The Milwaukee plant, which will handle 85 million gallons per day dry weather flow and is complete with power house, pumping station and elaborate facilities for dewatering and storing sludge, is located on a site of 30.6 acres. The area occupied solely by aeration tanks, settling tanks and their connecting conduits is less than 12 acres.

Eddy[1] has compared the areas and spaces required for three different types of treatment works for a city of 600,000, as follows:

	Acres	Cubic feet
Settling tanks, sludge beds and intermittent sand filters	800	140,000,000
Imhoff tanks, sludge beds and trickling filters	60	17,000,000
Activated sludge process	10	5,000,000

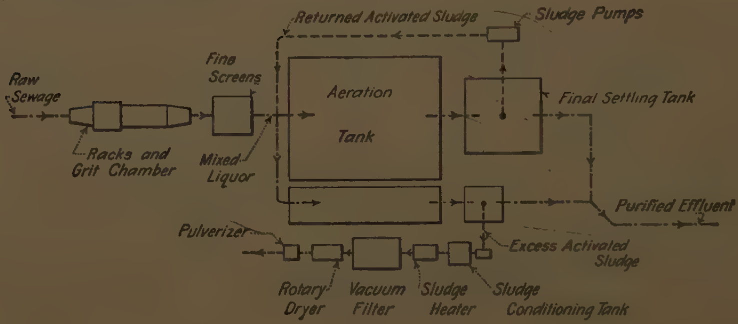
TYPICAL PLANT LAYOUTS

In Diagrams A, B and C in Fig. 65 are shown in diagrammatic form various typical layouts for activated sludge plants. Diagram A outlines a plant with racks, grit chamber and fine screens, preliminary to the aeration tank, and a complete dewatering plant for handling the excess activated sludge. This layout is generally similar to the Milwaukee plant and one interesting feature is the provision of an aeration unit and final settling tank so that the excess activated sludge may be passed separately through them and given such period of aeration as may be found best for obtaining a sludge in proper condition for dewatering.

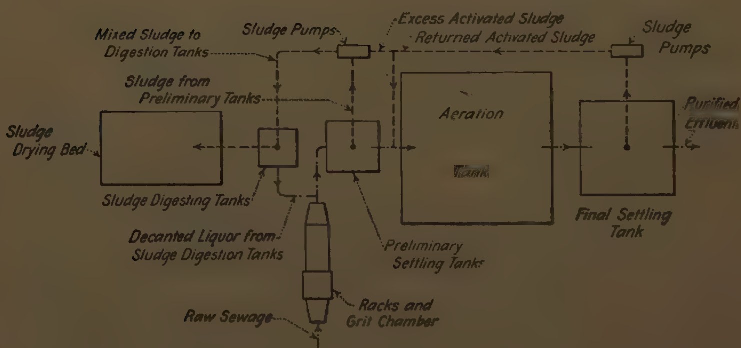
Diagram B shows the layout of a plant with preliminary settling tanks, racks and grit chamber in advance of the aeration units. Separate sludge digestion tanks are also provided, together with sludge drying beds, and these digestion tanks are arranged to receive both the excess activated sludge and the raw sludge from the preliminary settling tanks. In this particular layout, the excess sludge is delivered directly to the digestion tanks, but in some cases, it might prove desirable to discharge it into the influent of the preliminary tanks and allow it to settle out with

[1] Engineering News-Record, Vol. 92, p. 695, Apr. 17, 1924.

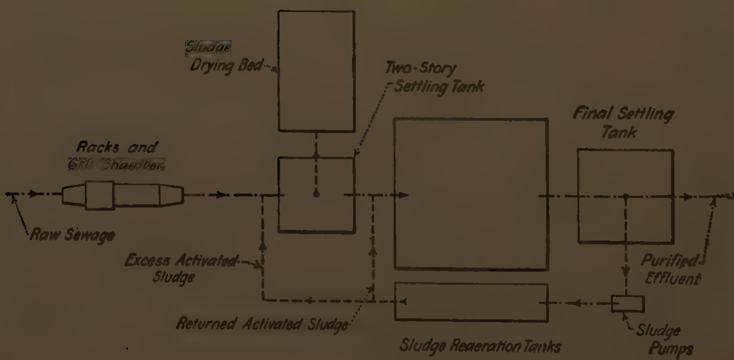
the raw sludge. This is the scheme adopted for the Chicago (North Side) plant.



A



B



C

FIG. 65.—Schematic drawings of activated sludge process.

In Diagram C a layout is shown with the two-story settling tanks in advance of the aeration units, together with sludge dry-

ing beds. The excess activated sludge is returned to the influent of the two-story tanks and settled together with the raw sludge, the two being digested together in the lower portions of the tanks. This layout also shows the arrangement for reaeration of the activated sludge from the final settling tanks before returning it to the aeration units.

POWER

Type of Power.—In view of the relatively large amount of power required for the activated sludge process, it is important that careful study be given to this factor in planning any installation. On the other hand, consideration must be given to practical operating conditions to the end that unduly elaborate arrangements are not provided for the purpose of securing what may turn out to be only a theoretical economy.

Undoubtedly in the case of most small plants and perhaps many of medium size, electric power, where it is fairly reliable and can be secured at a reasonable rate, will prove more satisfactory, particularly on account of the relatively simple and reliable equipment involved.

Where electric power is not suitable, Diesel engines will furnish an economical and reasonably reliable source of power and it may frequently happen that they will prove a valuable reserve to electrical power, or will make it possible to secure a better electric power load factor, as has been done at Houston.

When natural gas is available it may very likely prove the most advantageous power as in the case of smaller waterworks plants in some sections of the country. Study should also be given to the practicability of utilizing in gas engines the very substantial volume of gas evolved from sludge digestion tanks.

For the larger works, steam power will generally prove the best, particularly when the methods of sludge treatment require heat. Both the Milwaukee and Indianapolis plants are equipped with high-class, efficient, modern, steam plants and steam-driven equipment. At times, a steam plant may have a decided advantage in moderate-sized plants, due to the facility with which gas from sludge digestion tanks may be burned under the boilers. Since such gas varies in amount and heating value at different seasons of the year, its use in gas engines is not so simple.

Power for Compressing Air.—The probable air pressure required is determined by adding to the pressure, corresponding

to the depth of sewage in the tanks, the estimated friction losses in the air piping and diffusers, and allowing a reasonable factor of safety for unforeseen pressure requirements. In view of the relatively low pressures required for activated sludge plants, it is sufficiently accurate to compute the theoretical horsepower required for compressing the air on the basis of adiabatic compression, that is, without cooling. In Table 71 is given the theoretical power for compressing air adiabatically from atmospheric pressure (14.7 pounds per square inch), and at an initial temperature of 60° F., to various gage pressures. In determining the brake horsepower required, the mechanical efficiency of the device to be used for compression must also be taken into account.

TABLE 71.—POWER REQUIRED FOR COMPRESSING AIR

Final pressure of air, pounds per square inches	Theoretical work to compress 1 million cubic feet of free air, horsepower hours	Theoretical power to compress 100 cubic feet free air per minute, horsepower
1	72.3	0.43
2	144.0	0.86
3	200.8	1.20
4	265.2	1.59
5	325.8	1.95
6	384.7	2.31
7	442.5	2.66
8	490.2	2.94
9	543.4	3.26
10	596.5	3.58
12	697.1	4.18
14	785.4	4.71
16	875.9	5.26

AIR COMPRESSORS

Types of Air Compressors.—Various types of air compressors have been used in activated sludge plants, the principal ones of which are as follows:

(*A*) Single stage piston compressors.

(*B*) Positive pressure blowers.

(*C*) Nash Hytor compressors.
(*D*) Centrifugal compressors.

Piston Type Compressors.—At a number of the smaller English plants, high speed, single stage, piston compressors are in use, usually belt driven from electric motors. This type is moderately efficient but has the serious disadvantage that it is difficult to keep cylinder oil out of the compressed air. For capacities above 2000 cubic feet per minute, piston compressors become needlessly cumbersome and expensive for the relatively low pressure needed for activated sludge plants.

Piston compressors at Manchester (Withington) with a capacity of 700 cubic feet of free air per minute against a normal working pressure of about 4 pounds per square inch, driven by 30 horsepower electric motors, have shown overall efficiencies on test of 50 to 55 per cent, measured from the switchboard and referred to the air horsepower for adiabatic compression.

Positive Pressure Blowers.—For medium-size installations, positive pressure blowers of the Root or Connersville type are well adapted. They possess relatively high efficiency (from 75 to 80 per cent in the larger sizes); are of comparatively simple and reliable design; and operate at speeds suitable for direct connection to steam or oil engines. For electric motor drive, it is commonly necessary to use chains, gears or belts unless slow-speed motors are used. These blowers do not introduce any oil or dirt into the air, if proper stuffing boxes are provided. The capacity cannot readily be varied to conform to varying air requirements, unless provision is made for economically varying the speed. Positive pressure blowers are built in various sizes with capacities ranging from 100 to 15,000 cubic feet of free air per minute. They are not ordinarily recommended for air pressures in excess of about 8 pounds per square inch, and show the best efficiency when operating at pressures between 2 and 6 pounds per square inch.

At Houston, three positive pressure blowers of 3200 cubic feet per minute capacity against 5 pounds pressure have operated satisfactorily for several years. Two are connected to 150 horsepower electric motors and one to a 150-horsepower Diesel engine. The overall efficiency of these units from the switchboard and referred to adiabatic air horsepower is 50 to 55 per cent.

Nash Hytor Compressors.—For the smaller installations, the Nash Hytor Compressor is a simple, reliable and efficient machine.

Due to the fact that the rotor revolves in water, the air is quite thoroughly washed during compression. A suitable separator furnished with the compressor removes any water entrained in the compressed air. These compressors are adapted to pressures ranging from 3 to 15 pounds per square inch, but give their best efficiency at pressures from 8 to 12 pounds. They are regularly manufactured in nine sizes, varying in capacity from 30 to 3000 cubic feet per minute capacity, although somewhat larger sizes are built to order. They operate at speeds similar to positive pressure blowers. Compressors of this type are in satisfactory use at the Des Plaines and Calumet plants at Chicago and at Gastonia, N. C.

Centrifugal Compressors.—Centrifugal compressors, otherwise known as turbo-compressors, are excellently suited to medium and large-sized plants and recently satisfactory units of comparatively small size have been built. They operate at comparatively high speeds adapted for direct connection to steam turbines or high-speed electric motors. Such units occupy relatively little room for their output, are fairly free from vibration and require comparatively light foundations. Due to their simple construction and absence of rubbing or wearing surfaces, valves and springs, they require a minimum of attendance and oiling. At constant speed, these compressors will maintain approximately constant pressure for widely varying quantities of air, and without a serious loss in efficiency, the delivery being simply controlled by a gate in the discharge pipe. Unless it is possible to adjust the speed, as with a steam turbine, it is essential to know closely the maximum pressure against which such compressors will be called on to operate.

The Chicago (North Side) plant, will be equipped with four centrifugal compressors of 40,000 cubic feet per minute capacity and three of 30,000 cubic feet against 7.75 pounds per square inch gage pressure, all driven by synchronous motors, at 3600 revolutions per minute.

The Indianapolis plant has three steam-turbine-driven centrifugal compressors of 18,000 to 24,000 cubic feet per minute capacity, against 7.5 pounds gage pressures. With steam at 225 pounds pressure and 100° superheat, these units are guaranteed to deliver 1000 cubic feet of air for 7.67 pounds of steam.

The Milwaukee plant has four steam-turbine-driven centrifugal compressors of 35,000 cubic feet per minute capacity against 10

pounds gage pressure. With steam at 200 pounds pressure and 100° superheat, these units on test showed a steam consumption of 10.98 pounds per brake horsepower, including auxiliaries, or 10.11 pounds per 1000 cubic feet of air. The test efficiency of the compressors alone was 66.3 per cent. The interior of the Milwaukee Power House is shown in Fig. 66.

FIG. 66.—Interior of power house, turbo-driven blowers in foreground, Milwaukee, Wis.

Air Washing.—It is highly important that all air should be purified which is to be diffused through "Filtros" plates. At Indianapolis spray air washers are installed on the air intakes to the blowers. This equipment is guaranteed to remove 99 per cent of all dust and floating particles contained in the air. At the Des Plaines plant, Chicago, the air going to the blowers is screened through duck, supported on wooden slats, about 0.25 square foot being provided for each cubic foot per minute. An air washer is also provided. At Milwaukee trouble was encountered with air washers in severe cold weather due to freezing, and air filters consisting of metallic media coated with a light oil

known as "Viscosine" were substituted with satisfaction. At the Chicago (North Side) plant oil cleaners, as well as air washers and heaters, are provided. The conditioning of the air is a factor in maintaining the motor efficiency.

REPRESENTATIVE PLANTS

For purposes of illustration descriptions are given of the four principal plants in the United States in all of which compressed air is used for agitation. In the English plants[1] described, use is made of mechanical means for agitation. This should not be construed to indicate that in England the compressed air method is in disfavor. Many of the important plants and projects are of that type, particularly those at Worcester, Manchester, Glasgow, Stoke and Reading. A new 18 million gallon project for Manchester is now before the Ministry of Health. Compressed air will be used for 16 million gallon capacity and in two 1 million gallon units there will be the Simplex aerator type and some form of the paddle wheel type, respectively.

Houston, Tex.[2]—Two activated sludge plants, having a combined capacity of 15 million gallons daily, were placed in operation by the city of Houston in 1917 and 1918. One of these, the North Side plant, consists of 4 units and the other, the South Side plant, consists of 2 units. Each unit has a designed capacity of 2½ million gallons daily, and includes an aeration tank, 10 settling tanks, and a sludge reaeration tank.

The North Side plant treats both domestic and industrial sewage, as well as accumulations of night soil from about 10,000 dry closets. The South Side sewage is domestic and comparatively weak. About 2.2 cubic feet of air per gallon of sewage treated are being used at the former plant, and less than 2 cubic feet at the latter. The effluent contains less organic matter than the water into which it discharges. These facts are illustrated in the following figures:

[1] For a comparison of some features of American and English practice on this and other processes, see "The Present Status of Sewage Treatment in England" by Fuller, Engineering News-Record, Vol. 90, pp. 206, 252 and 299, February, 1923; Surveyor, Vol. 63, p. 191, February 23, 1923.

[2] Engineering News, Vol. 77, p. 237; Feb. 8, 1917. Also International Conference on Sanitary Engineering, London, 1924, p. 81.

Results in parts per million	North Side plant				South Side plant			
	1922		1923		1922		1923	
	Sew.	Eff.	Sew.	Eff.	Sew.	Eff.	Sew.	Eff.
Nitrogen as free ammonia	22.5	8.5	19.2	7.2	16.9	4.3	16.5	5.0
Nitrogen as nitrates....	0.0	2.9	0.0	4.1	0.0	9.9	....	11.3
Biochemical oxygen demand, 1 day	55	4.4	36	3.6				
Biochemical oxygen demand, 5 day	161	11.3	120	8.2				
Suspended solids........	348	29.2	272	34.3	166	7.5	145	9.1

Each aeration tank is 18 by 280 feet in plan, and 9.75 feet deep over the aerators, and contains about 340,000 gallons. At its full designed capacity, it has a detention period of somewhat more than 2½ hours, after making an allowance of 20 per cent for returned sludge. The floor is of the ridge and furrow type. Diffusers of 12- by 12- by 1½-inch Filtros plates are set in containers in rows across the tank spaced 5 feet apart. The containers were originally of cast iron, but these were replaced in 1920 with concrete containers on account of clogging of the plates by iron rust. The air is filtered through 8-ounce duck and canton flannel. The ratio of plate area to tank area is about 1:7.

From the aeration tanks the mixture of sludge and sewage flows to the settling tanks through a channel 104 feet long, having aerating plates placed at intervals in the bottom. The settling tanks (Fig. 67) are 10 by 18 feet 10 inches in plan; an area corresponding to about 1300 gallons per square foot per day at the designed rate. They are about 22 feet deep below the sewage level and have hopper bottoms, from which the sludge is removed by air lifts. The sewage is admitted below the surface at one side of the tank and flows across and upward over the adjustable weirs at the other side. The estimated velocity at full rated load is about 0.4 inch per second. The walls of the hopper bottoms slope in the approximate ratio of 2⅓ vertical to 1 horizontal. Even with such steep slopes sludge settles upon the surface of the walls and septic conditions develop in these deposits unless they are removed by brushes.

The settled sludge is removed to the reaeration tank, 9 by 280 feet in plan, and identical, except for width with the aeration tank. Excess sludge not returned to the aeration tank is pumped

from the reaeration tank. The excess sludge has been disposed of in the past in sludge lagoons without nuisance.

Indianapolis, Ind.—The Indianapolis activated sludge plant[1] is designed for an average dry weather flow of 50 million gallons, and is capable of expansion to take care of 72 million gallons.

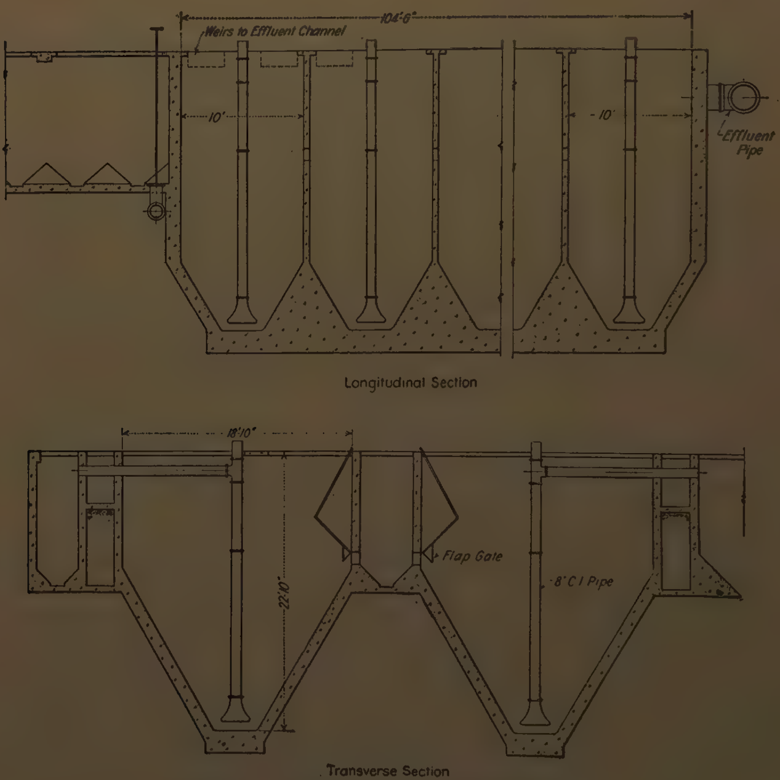


FIG. 67.—Settling tanks, Houston, Tex.

It is preceded by a clarification plant consisting of grit chambers and fine screens. A small portion of the sewage flow, called the concentrate, which has not passed through the screen and which contains the screenings, is settled in small sedimentation tanks, called concentrate thickener tanks (see Fig. 68). The solids are removed from these tanks by means of slow-moving flight conveyors, and the liquid is returned to the screened sewage.

[1] Eng. News-Record, Vol. 91, p. 258; Aug. 16, 1923.

There are 7 aeration tanks, each 238 feet long and 15 feet deep. (See Fig. 69.) Two of the tanks have two full longitudinal passes, and five have four passes, each channel being 20 feet wide.

Fig. 68.—Concentrate thickener tanks, Indianapolis, Ind.

Fig. 69.—Aeration tanks, Indianapolis, Ind.

One of the smaller tanks may be used for reaeration or retempering of the sludge. Three longitudinal rows of diffuser plates are set in recesses in the floor near one side of each channel. The

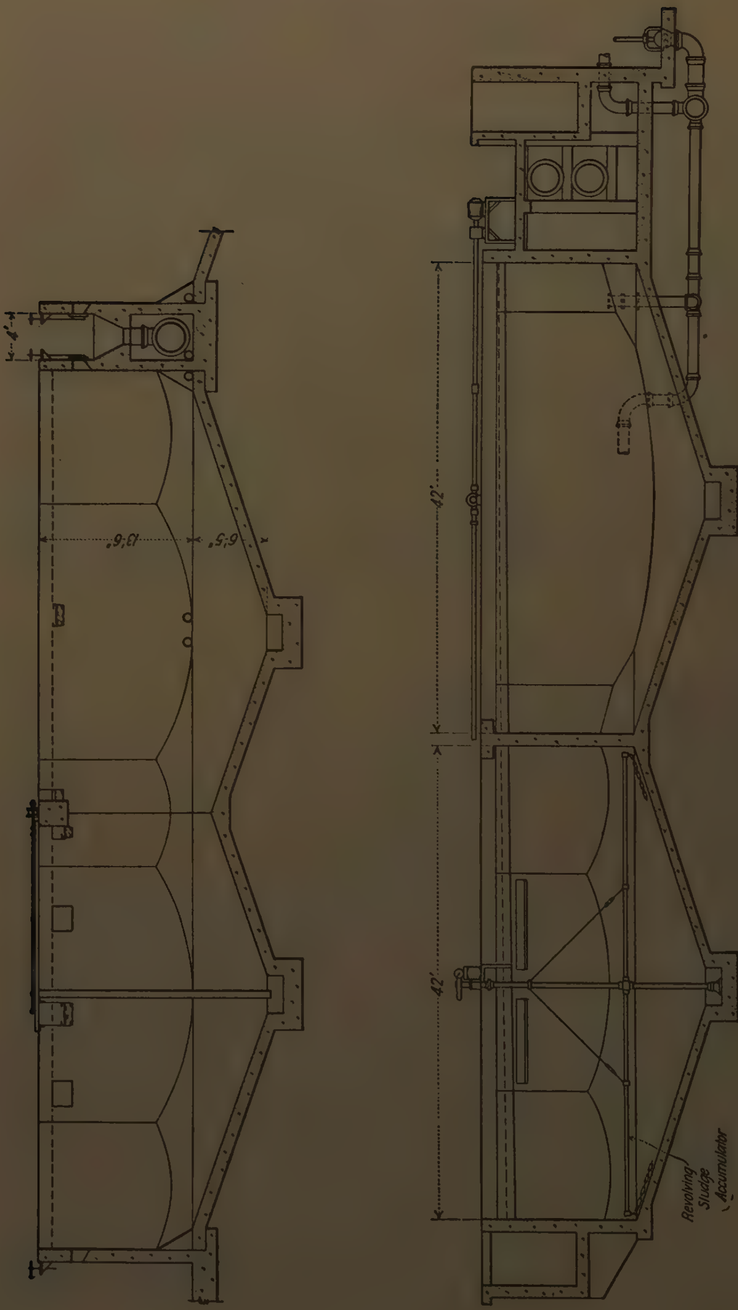


FIG. 70.—Settling tank, Indianapolis, Ind.

diffuser area is 7.5 per cent of the tank area. Fifty diffuser plates are operated from one air valve.

The top corners of the tanks and the bottom corner opposite the diffuser plates are filled in, forming deflectors to induce a rotary motion, which motion becomes spiral as the sewage passes through the tank. Experiments showed that with the use of 1 cubic foot of air per gallon a velocity of 2 feet per second would be maintained at the surface and across the floor of the tank.

FIG. 71.—Aeration tanks, Milwaukee, Wis.

The type of separating tank used at Indianapolis is somewhat novel. As shown in Fig. 70, each unit comprises two octagonal sections with moderately steep conical bottoms.

Including 20 per cent returned sludge, they are designed to operate at 1650 gallons per day per square foot of area. With an assumed maximum flow of 150 per cent, this rate would be increased to 2340 gallons per square foot of area. The settling period under average conditions, including allowance for sludge, approximates 97 minutes and for maximum conditions 53 minutes.

The sludge removal mechanism consists of two revolving elements for each tank, two units being driven from a single motor. Sweeping chains are provided to keep the sludge from adhering to the bottom. By producing a slow rolling movement of the sludge these chains assist in concentration in the cones. Each double tank is equipped with one 2-horsepower electric motor, which through spur reduction and worm gearing rotates the elements once in 19 minutes.

Milwaukee, Wis.—The city of Milwaukee put into operation in 1925 an activated sludge plant[1] designed to treat an average future flow of about 85 million gallons daily and a maximum of about 165 million gallons. The preliminary treatment consists of coarse screens, grit chambers and fine screens. The activated sludge layout includes 24 aeration tanks and 15 settling tanks. There are no reaeration tanks.

Each aeration unit is 236 feet long, 44 feet wide and 15 feet deep from top of liquid to top of diffuser plates. Its capacity, based on a rate of 15 million gallons per acre per day, is about 3.6 million gallons daily. The time of detention, after allowing for 20 per cent of returned sludge, is about 6 hours. A longitudinal baffle is provided, so that the sewage travels twice the length of the tank or a total of about 475 ft.

The bottom of the tank is of the ridge and furrow type. Filtros diffuser plates, set in concrete containers, extend across the tank at the bottoms of the furrows in rows 4 feet apart. A row of diffusers is also placed longitudinally along the center of each of the two compartments of the tank. The ratio of diffuser area to tank area is 1 to 4. A typical unit is shown in Fig. 71.

The settling tanks are designed on the basis of one square foot of liquid surface for each 1600 gallons of maximum sewage flow per day, not including any allowance for returned sludge. Their depth is 15 feet, which depth was considered necessary in order to allow adequate storage for sludge during maximum flow, based on a uniform rate of sludge withdrawal. Each of the 11 large tanks is octagonal at the top, and the corners and sides are sloped inward to form a circular bottom 98 feet in diameter. The mixed liquor enters the tanks from opposite sides through four gates on each side, 8 feet by 9 inches in size, and 3½ feet below the surface. The effluent is drawn off at the surface over three troughs extending across the tank at right angles to the direction of flow. Each

[1] Trans. Am. Soc. C. E., Vol. 85, p. 837.

tank is equipped with Dorr thickener apparatus for removal of sludge, which is done by gravity (Fig. 72).

The channels feeding the aeration tanks, those carrying the mixed liquor from the aeration tanks to the settling tanks, and those for returning the sludge to the aeration tanks, are provided with diffuser plates in the bottom.

Chicago, Ill.[1]—The North Side activated sludge plant, which is designed to treat the sewage of a population of 800,000, with an average sewage flow of 219 gallons per capita daily, is now under construction. Preliminary treatment consists of bar screens, grit chambers and settling tanks with Dorr clarifiers.

FIG. 72.—Settling tanks, Milwaukee, Wis.

The aerating tanks are designed for a contact period of 6 hours. There are 36 tanks each 417 feet long and about 33 feet wide and about 15 feet deep from surface of liquid to top of diffuser plates. These tanks have flat bottoms and are arranged for spiral flow of the sewage. Each unit is divided into two channels by means of a longitudinal baffle wall. In each of the two channels, two longitudinal rows of diffuser plates are laid along one side. Longitudinal deflector baffles are built in the corners at the top and one side of the bottom to cut out dead spaces. The estimated use of air is ¾ cubic foot per gallon of sewage.

The sludge settling tanks are 77 feet square, about 12 feet deep below the water line along the periphery, and with the bottom

[1] Kelly, Engineering News-Record, Vol. 96, p. 394, Mar. 11, 1926.

sloping to a depth of about 16 feet at the center. They are provided with Dorr thickeners for continuous sludge removal. The sewage enters on opposite sides of each tank, over six inlet weirs, 3½ feet wide, spaced uniformly and provided with downward deflecting baffles which admit the sewage at a level about 4 feet below the water line. It flows horizontally and upward and passes out over weirs which form the sides of three channels parallel to the inlet sides; one channel being at the middle of the tank and the other two at 8½ feet on either side of the middle.

FIG. 73.—General view, Sheffield, Eng. plant, 1925.

Sheffield, England.—As a result of several years successful experience with a trial plant of 500,000 Imperial gallons capacity designed by John Haworth, General Manager, Sewage Disposal Works, Sheffield has completed several units of works of 15 million gallons (Imperial) per day capacity of the activated sludge type. It is interesting that these works were determined upon in place of percolating filters which had previously been sanctioned but were held up by the war.

The interesting feature is the type of aeration or circulating tank. These units are being constructed in the shells of existing primary contact bids. Each unit is approximately 265 feet long by 130 feet wide, with a depth of 4 feet 5 inches below the water

line and has a capacity of 900,000 Imperial gallons. They are divided into 20 to 22 longitudinal channels, each 6 feet wide, by concrete division walls, having an average thickness of 3½ inches. The channels are connected at the ends with semi-circular sections with a transverse channel across one end in such a manner as to form one continuous channel some 5540 feet in length. The division walls are bulged at their ends to restrict the channel. Haworth considers this feature important to maintain the waves as the sewage passes around the end.

FIG. 74.—Older paddle type of aeration, Sheffield, Eng.

Sewage mixed with activated sludge is circulated in these channels by paddle wheels which are located near the middle of each channel and carried on two shafts turning in opposite directions. (See Figs. 73 and 74.) Each paddle wheel is 10 feet in diameter, 2 feet 6 inches wide and constructed of steel angles. A cover similar to those on a side-wheel steamer and built of fibro-asbestos sheeting on a steel angle frame encloses each wheel. The wheels are rotated at a speed of 15 to 16 revolutions per minute by electric motors and spur reduction gears driving each line shaft. The paddle wheels produce short waves and circulate the sewage in the channel at a non-depositing velocity. The

effluent is weired off the transverse channel and settled in tanks of the Dortmund type, the sludge being returned by motor-driven pumps which operate automatically as the level in the sludge well varies.

The Sheffield sewage contains various trade wastes, particularly those from iron and steel industries. Iron salts are usually present and frequently the sewage has an acid reaction. Spent ammonia has at times been present in substantial quantities.

In February, 1926, the authors found that the sewage was first settled for 6 to 8 hours. With an aeration period of 16 hours, the power consumption was then 24 horsepower per million Imperial gallons. The settling period for the aerated liquid and sludge was about 4 hours for dry weather flow. About one-third of the separated sludge was returned to the aerating tank in which the activated sludge formed 15 per cent by volume after settling 1 hour. The excess sludge from the final settling tanks was sent to the preliminary settling tanks, the sludge from which, after drying on ash beds, is used on farm lands. Haworth was then experimenting with a decreased flow so as to provide an aerating period of 24 instead of 16 hours and with some of the paddles removed from the wheels. The purpose was to ascertain if the longer aeration period with a reduced horsepower to 15 per million imperial gallons might prove practicable under local conditions. There are about 15 plants of this general type either built or building.

The effluents secured have been uniformly satisfactory, notwithstanding the difficult sewage dealt with, and comply with the requirements of the River Authorities. A number of smaller plants of this type have also been built in England.

Simplex Aeration Process at Bury, England.—The simplex aeration unit consists of a light vertical tube 3 feet in diameter, fixed in a tank and resting on feet so as to leave a 6-inch space under the bottom edge, thus permitting the mixture of activated sludge and sewage to enter from the outside and pass up the tube. At the top of the tube, a revolving cone 6 feet in diameter is suspended, provided with vanes and an opening corresponding to the top of the tube. This cone revolves on a vertical shaft which is driven through gearing and as it revolves, liquid is drawn up through the tube and thrown out in a film which strikes the surface of the sewage in the tank and thoroughly agitates and aerates it. There is a continual circulation of the sewage up the

tube and returning down the outside so that all portions are successively agitated and exposed to the air.

A unit of 50,000 Imperial gallons daily was operated for several years. The authors found in January, 1926, that a new plant had been in service for about 11 months treating about 1.2 million Imperial gallons daily. The aerating tanks are 9 feet deep and have a capacity of 492,000 gallons; and final settling tanks are 22 feet deep, holding 225,000 gallons. The rated period of aeration is about 10 hours and the period of settling about 6 hours, dry weather flow. The returned sludge is 10½ per cent measured after 1 hour's settling. The aerators are of the Simplex type,

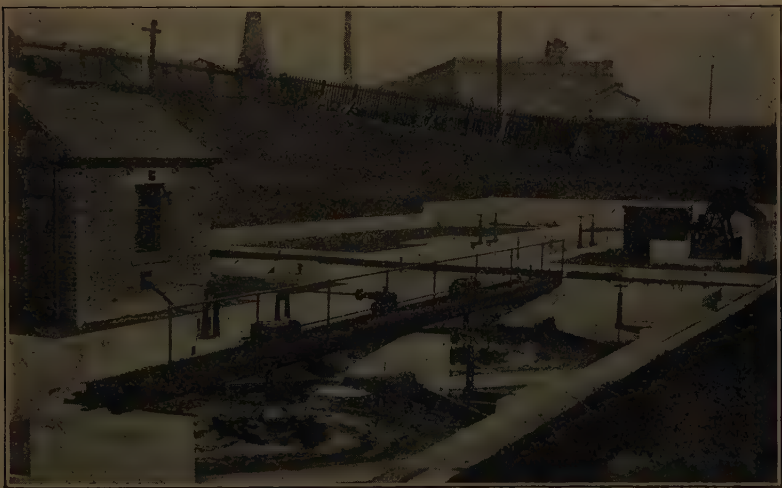


FIG. 75.—Simplex aerators, Prestolee, Eng.

designed by Bolton and built by the Ames Crosta Company. The power consumption is stated to be 20 horsepower per million Imperial gallons. Similar plants are in service at Prestolee (see Fig. 75), Bolton and Turton.

Birmingham, England, Bio-aeration Plant.[1]—At Birmingham, a short preliminary treatment by the activated sludge process is being used for a portion of the settled sewage prior to treatment by trickling filters. The high rate at which this activated sludge effluent can be treated on trickling filters makes possible the effective utilization of the very large investment in filters already

[1] "Partial Purification of Sewage by Activated Sludge," by H. C. Whitehead, Surveyor, Vol. 68, p. 449, November 20, 1925.

made at Birmingham. The sewage and activated sludge are passed successively through a series of parallel flocculating channels, each 4 feet 8 inches wide and 4 feet 4 inches deep, constructed on a gradient to give about 1 foot per second velocity and with a combined length to give 1 hour flocculation. There are small circular chambers at each end of the flocculating channels which are equipped with Hartley aerators. (See Fig. 76.) Inclined oblique baffles have been installed in the flocculating channels to induce spiral flow.

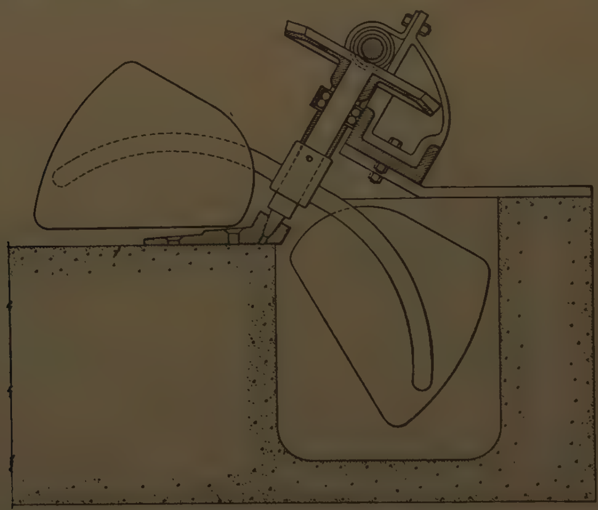


FIG. 76.—Hartley paddle.

The flocculated liquor goes to settling (humus) tanks of the hopper-bottomed type and the sludge removed by these tanks goes to a reaeration tank where it is agitated for several hours. This tank is rectangular in plan with five Simplex aerators arranged along the center in rows, the sludge passing by them successively in its course from one end of the tank to the other.

Essen-Rellinghausen, Germany.—Since the latter part of 1925 an activated sludge plant has been in operation at Essen-Rellinghausen in the Ruhr district for a population of 45,000 people. The plant is equipped with a combination of mechanical aeration by paddle and by compressed air. About 15 per cent of returned sludge is used and the period of aeration is 3½ hours. Imhoff and Fries[1] report that the results of operation so far have been

[1] Technisches Gemeindeblatt, Vol. 29, No. 3, May 5, 1926.

excellent. A similar apparatus was earlier tried at Argo, Ill. on corn products wastes, but was not found to be advantageous.

The details as to this particular installation together with certain comparative data for English and American plants, prepared by Imhoff and Fries, are shown in Table 72. They are suggestive, but in the absence of relative strengths of sewages and effluents, construction details and prices, use made of earlier plants, etc., they should be used with caution for comparisons elsewhere.

TABLE 72.—COMPARATIVE DATA ON ACTIVATED SLUDGE PLANTS
(Imhoff and Fries)

Plant	Essen-Rellinghausen	England			United States	
		Bury	Sheffield	Manchester-Withington	Indianapolis	Milwaukee
Inhabitants	45,000	29,000	520,000	29,000	360,000	575,000
Sewage flow, cubic meters per day	22,000	3,650	70,000	6,500	200,000	415,000
Sewage flow, liters per capita	600	125	135	225	550	720
Nature of preliminary treatment and time of clarification	Emscher tanks 20 minutes	Settling tanks 6 hours	Settling basins 6 hours	Settling basins 40 minutes	Settling basins and screens	Screens and grit chambers
Nature of aeration	Revolving paddles and compressed [illegible]	Simplex aeration	Revolving paddles	Compressed air	Compressed air	Compressed air
Aeration period with 15 per cent returned sludge, in hours	3.5	13	15	7	[illegible]	[illegible]
Construction cost in gold marks without pre-treatment:						
Total	300,000	200,000	5,000,000	236,000	9,000,000*	38,000,000*
For 1 inhabitant	6.7	7	10	8	25	67
For 1 cubic meter of sewage per day	13.5	55	70	[illegible]	45	[illegible]
Consumption of air for 1 c.b.m. of sewage in cubic meters	1	....	....	6	7	
Required power for aeration and pumping sludge back in terms of horsepower units, total	40	30	550	27		
For 1000 cubic meters of sewage per day	1.8	8.3	7.8	4.2		
For 1,000,000 gallons (English) sewage per day	8.1	24	35	19		
For 1,000,000 gallons (U. S.) per day	7	20	29	16		

* With preliminary clarification.

CHAPTER XXXIX

DISPOSAL OF ACTIVATED SLUDGE

SYNOPSIS

1. Volume.—The excess activated sludge from the separating tanks contains 80 to 90 per cent of the suspended solids in the sewage entering the aerating tanks and has a moisture content of 97 to 99.5 per cent. The volume ordinarily ranges from 5000 to 15,000 gallons per million gallons of sewage treated, but, by resettling, the moisture content can usually be reduced to about 97 per cent, which reduces the volume of sludge about one half.

2. Condition.—The high moisture content and the gelatinous character of the sludge make it difficult to dewater; and the sludge is liable to putrefy within 12 to 24 hours after deposition in the separating tanks.

3. Methods of Disposal.—Various methods are in use as follows:

1. Application to drying beds as at Sheffield and Reading, England.
2. Trenching as at Withington, England, and Mamaroneck, N. Y.
3. Dewatering and drying for sale as fertilizer as at Milwaukee.
4. Lagooning as at Houston, Tex.
5. Return to inlet of main settling tanks and treatment with other sludge as at Hanley and Sheffield, England.
6. Application in wet condition to land as a fertilizer as in India and China.
7. Digestion either in two-story tanks as at Essen and Chicago or in separate digestion tanks or basins after mixing with other sludge, as at Indianapolis.

4. Drying Beds and Trenching.—It is feasible to dry activated sludge on specially prepared sand beds, and in some cases in trenches, but owing to the large area required and the small doses which can be applied it is probably not economical except perhaps for very small plants.

5. Dewatering for Fertilizer.—The dewatering of this sludge by suitable vacuum filters or sludge presses to 80 to 85 per cent moisture content, and the subsequent drying in rotary heat driers to 10 per cent or less moisture content, for use as a fertilizer, are practicable but involve an elaborate and complicated plant and careful conditioning of the sludge. Furthermore, except in large plants and under special conditions, it is uncertain whether the cost will be offset by the market value of the product.

6. Lagoons.—The disposal of sludge in lagoons, abandoned quarries or similar depressions is only possible at certain locations and is at best a temporary expedient.

7. Digestion of Activated Sludge.—The digestion of the excess activated sludge together with the sludge from preliminary settling tanks, either in two-story tanks or in separate sludge digestion tanks, shows strong promise of proving the most satisfactory and economical method of disposal in most cases, except possibly at some of the largest plants. The collection of gas from such sludge digestion will eliminate the possibility of odors and make a substantial reduction in operating costs when used for power or sold for heating and lighting. The sludge can undoubtedly be dried and disposed of as readily as that from two-story tanks and should have fully as high fertilizer value.

QUANTITY OF SLUDGE PRODUCED

The quantity of excess activated sludge produced varies widely with different sewages and percentages of water content. As delivered from the separating tanks, the sludge seldom has less than 97 per cent water and frequently the water content is 99 or even 99.5 per cent. By careful resettling, the water content of the sludge can usually be reduced to 97 per cent.

The quantity of solid matter depends, of course, upon the quantity of suspended and colloidal matter in the sewage treated and also upon the degree of completeness of the treatment. At Milwaukee, it is expected that 2000 to 2500 pounds of dry solids per million gallons of sewage will be obtained, the suspended solids in the sewage ranging from 250 to 300 parts per million. In general the dry solids in the sludge will probably amount to 70 to 90 per cent of the suspended solids in the sewage aside from the effect of certain trade wastes or of unusually complete preliminary treatment, as in settling tanks.

To show the wide variation in quantity to be expected, Table 73 shows the volume of sludge in gallons per million gallons of sewage per day for different amounts of suspended matter in the sewage and different water contents of the sludge on the basis of dry sludge solids being 90 per cent of the suspended matter.

TABLE 73.—GALLONS OF SLUDGE PER MILLION GALLONS TREATED

Suspended solids in sewage, p.p.m.	Dry sludge solids, pounds	Percentage moisture content of sludge				
		97	98	98.5	99	99.5
100	750	3,000	4,500	6,000	9,000	18,000
200	1,500	6,000	9,000	12,000	18,000	36,000
300	2,250	9,000	13,500	18,000	27,000	54,000
400	3,000	12,000	18,000	24,000	36,000	72,000
600	4,500	18,000	27,000	36,000	72,000	144,000

DEWATERING ACTIVATED SLUDGE

Owing to the high water content and also the gelatinous character of the sludge solids which causes a large part of the water to be held in the sludge particles themselves, dewatering the sludge has proved the most difficult and troublesome problem of the activated sludge process.

Due to the unoxidized condition of the interior of the particles of activated sludge, putrefaction may set in within 12 to 24 hours after deposition in the separating tanks. The wide variation depends upon the preparatory treatment of the sewage, completeness of purification, temperature, biological factors, etc. It is important to realize this characteristic in disposing of the sludge.

A very considerable amount of study has been given to the problem, particularly at Milwaukee and Chicago, and the various methods considered are set out in the following outline by Pearse:

Primary Removal of Water

1. Air drying on prepared sand beds.
2. Filtering.
   a. Through fine wire mesh (Maclachlan).
   b. Through Filtros plates.
   c. Through absorbent material.

3. Filtering with aid of additional pressure.
    a. Hydraulic pressure applied to liquid.
        (1) Chamber or leaf filter press.
        (2) Kelly filter.
    b. Hydraulic pressure applied to bags.
        (1) Worthington.
        (2) Berrigan.
    c. Vacuum filters.
        (1) Rotary leaf or American.
        (2) Rotary drum or Oliver.
4. Centrifuge.
    a. Intermittent.
    b. Continuous.
5. Flotation.
6. Spraying (Bailey).

Secondary Removal of Water

1. Rotary heat dryer.
    a. Direct
    b. Direct-indirect.
    c. Steam.
2. Traveling belt dryers.

DRYING ON SAND BEDS

It has been found practicable at a number of places to dry activated sludge successfully on suitable sand beds when the weather is favorable, but it is essential to apply it in thin layers so that the economy of the procedure at works of any size is doubtful. It is probable that the character and condition of the sludge at different places has a good deal to do with successful drying.

Haworth at Sheffield found that specially prepared ash filters gave the most practicable results in dewatering sludge. When filled to a depth of 8 or 9 inches with wet sludge, such filters yielded a portable cake within a few days. In dry weather 2 or 3 days sufficed to give a cake readily lifted with a fork. He estimated that 1 square yard of ash filters per seven or eight persons would suffice.

At Reading, England, it is planned to dry the sludge from 100,000 people on prepared ash filters and return the effluent from the filters for treatment with the incoming sewage. One square yard per four persons is being provided.

At Mamaroneck, N. Y., where a small activated sludge plant[1] was put in service in 1925 and operated only during the summer season for the protection of nearby bathing beaches, no difficulty has been found in disposing of the excess sludge by pumping to plowed furrows in sandy fill adjacent to the plant and without nuisance. It is anticipated that the same area of ground may be used for several seasons in this manner.

FILTERING OF SLUDGE

All filtering operations on activated sludge are relatively difficult, troublesome and expensive. Owing to the finely divided, viscous, gelatinous nature of the material, it is difficult to find a filtering medium which will retain the solid matters and yet not clog too quickly. This fact taken in connection with the large water content means that large filter areas have to be provided and the yield per unit of area is disappointingly small.

The effectiveness of filtering depends very materially upon the condition of the sludge, which varies widely with different sewages and seasonal temperature ranges and is likewise related to the amount of aeration it receives. Industrial wastes and especially oil also have a substantial influence on the nature of the sludge.

OUTLOOK FOR SUCCESSFUL SLUDGE FILTERING

Of the various filters outlined the Oliver rotary vacuum filter has shown the greatest promise to date and is in operation on a large scale at the Milwaukee plant. A unit of the same size as the Milwaukee filters has been in operation at the Calumet plant, Chicago, since July, 1923. It has given excellent results, using alum as a coagulant. Two filters have been in operation at Pasadena[2] since early in 1925. They have handled all the sludge from about 90,000 population continuously. Another has recently been added. Alum has been used as a coagulant. An American rotary leaf filter has been installed at Indianapolis, but results with it are not available. It seems probable that

[1] For description see The Nations Health, Vol. VIII, No. 1, p. 1, January, 1926.

[2] For a description with cost data of the activated sludge plant serving Pasadena, South Pasedena and Alhambra and located on the old Pasadena sewage farm in Alhambra, Calif., see Engineering News-Record, Vol. 95, p. 714, October 29, 1925.

filters of the continuous rotary vacuum type will prove the most satisfactory in the future for sludge dewatering, although the Berrigan press, and to a lesser extent, the Worthington press, have proved reasonably successful and may have a useful field particularly in smaller plants, where an intermittent machine can be worked more economically with the relatively small and varying quantities of sludge.

The other types of equipment outlined have not given promise of successful adaptation to activated sludge dewatering, and the results with various types of centrifuges as well as flotation and spraying systems have not been encouraging.

VACUUM FILTERS

The Oliver continuous filter (Fig. 77) consists of a drum divided into sections and covered with filter cloth. The drum is revolved

FIG. 77.—Oliver continuous filters, Milwaukee, Wis.

once in 4 to 15 minutes, depending upon whether the sludge filters quickly or not, in a tank filled with sludge to various depths. The area of the cloth submerged may be varied from

15 to 40 per cent at will. As each section becomes immersed, vacuum is applied which induces filtration through the cloth and picks up a coating of sludge ⅛ to $\frac{3}{16}$ inch thick. Vacuum is continued on the sections during most of the revolution to dewater further the sludge ribbon, and just before it goes down into the sludge tank, steam or air under pressure is admitted to force the sludge from the cloth.

At Milwaukee, the drums are 11 feet 6 inches in diameter and 14 feet long and are covered with 14-ounce twill cotton cloth, attached by winding with No. 14 wire, spaced 1 inch apart. In operation, this cloth lasts about 60 days. Provision is made for two vacuums, and in summer, when the sludge temperature is high, 11 inches of vacuum are applied to the sections while immersed and 22 inches during the balance of the revolution, while in winter this application is reversed. Arrangements are also provided for cleaning the cloth by spraying with water, steam or caustic soda solution and brushing. Each filter was designed for producing from 25,000 to 50,000 pounds of cake containing 80 per cent moisture per day. It is too soon to discuss large scale operations.

The American rotary leaf filter is similar in principle to the Oliver, except that rotating leaves or discs are employed divided into sections. It is built up to 14 feet 6 inches in diameter with eight discs.

HYDRAULIC PRESSES

Both the Worthington and Berrigan presses are arranged to apply hydraulic pressure to a series of bags filled with sludge. The Worthington press (Fig. 78) has bags filled at the top, suspended between built-up steel drainage sheets and squeezed by large platens worked by a toggle joint. The Berrigan press has bags filled from the bottom, suspended between drainage sheets of hard wood slats and squeezed by direct pressure on the heads of the press. The bags are made of burlap (8 to 12 ounces) and last from 30 to 45 days in operation.

Both types are in use at Chicago (Des Plaines), the Worthington press holding 18 bags on platens 5 by 8 feet and the Berrigan press holding 80 to 120 bags with platens 4 by 6 feet. The bags are filled and squeezed for several hours and when the cake has formed they are opened at the bottom and the cake drops out. With the Berrigan press, it is possible to control the thickness of

the cake and it is a more simple machine. Simplex plate presses with hydraulic pressure applied to the liquid sludge, like those in use for pressing sludge at chemical precipitation plants, have also

FIG. 78.—Worthington press.

been used successfully both at Chicago and Houston, although the breakage of plates and cloths has been annoying.

COMPARISON OF PRESSES AND FILTERS

The following data from Pearse give an idea of the relative performance of the different types in use at Chicago, although not strictly comparable on account of differences in sludge handled.

Press or filter	Filter area, square feet	Cake produced		Cycle, hours
		Pounds	Per cent moisture	
Simplex	1,815	4,400	78	7
Worthington	1,440	3,500	76	5
Berrigan	3,520	10,000	78	8
Oliver	495	1,400	80	Per hour

SLUDGE CONDITIONING

Elaborate investigations have been carried out at several places, but notably at Milwaukee, to develop a method of treating or conditioning activated sludge so that it can be dewatered at all times by presses or filters to 80 to 85 per cent moisture, in which condition it can be dried by heat. In summer, at Milwaukee, with a sewage temperature of 70° F., the sludge was readily dewatered, but in winter, when the sewage temperature dropped to 45° F. or lower, the sludge filtered more slowly. This was apparently due to the sludge particles being in a much finer state. The problem of coagulating such winter sludge so as to form larger particles was worked out by Wilson by the application of colloid chemistry, with these results:

By adding sulphuric acid until the sludge had a pH value of 3.4, (the iso-electric point of sludge at Milwaukee), it was possible to dewater at five times its normal rate. By adding aluminum sulphate, in addition to acid, it could be dewatered at eight times the normal rate. Finally, by heating the sludge to 180° F. after acidifying and adding aluminum sulphate, the coagulation of the fine particles was so complete that the rate of dewatering was increased forty times, but the acidification must precede the heating. Acidifying with phosphoric acid with a view to improving the fertilizing value of the sludge proved uneconomical on account of loss of acid in the filtrate.

At Chicago (Des Plaines), with cold sludge, use has been made of sulphate of alumina, 5 to 15 pounds per 1000 gallons of 98.5 per cent sludge, and has proved more beneficial than sulphuric acid (3.5 to 5.3 cubic centimeters per gallon).

At both Milwaukee and Houston, sulphurous acid has been used successfully as a conditioning agent, instead of sulphuric

acid, but has been abandoned on account of the fumes and difficulty of control. Ferric chloride has also proved efficacious.

Comparative results at Milwaukee, with different conditioning procedures, are shown in Table 74.

TABLE 74.—RESULTS OBTAINED WITH THE OLIVER CONTINUOUS VACUUM FILTER WHEN SULPHURIC ACID, SULPHUROUS ACID AND ALUMINUM SULPHATE WERE USED TO CONDITION THE SLUDGE FOR FILTERING

Temp., °F.	pH of the effluent from press	Pounds of 10 per cent moisture cake per 1 square foot of cloth per minute	Per cent moisture in press cakes	Per cent nitrogen as NH_3 in dry press cake	
				Total	Water soluble
		Sulphuric Acid			
Cold	3.4	0.0067	84.2	8.06	0.34
Cold	3.4	0.0078	85.7	8.06	0.78
100	3.5	0.0111	84.4	7.99	0.32
120	3.4	0.0144	83.0	7.45	0.44
140	3.4	0.0145	83.3	7.92	
160	3.4	0.0152	82.7	7.31	0.40
		Sulphurous Acid			
Cold	3.4	0.0075	84.1	7.65	0.56
Cold	3.4	0.0076	85.2	7.48	0.85
100	3.4	0.0124	85.0	7.65	0.41
120	3.4	0.0147	83.8	7.51	0.17
140	3.4	0.0168	82.7	6 97	0.15
160	3.4	0.0204	82.9	7.62	0.39
		Aluminum Sulphate			
Cold	5.0	0.0109	84.9	7.21	0.32
Cold	5.0	0.0118	85.5	7.34	0.63
100	5.0	0.0127	85.2	7.70	0.48
120	5.0	0.0172	85.6	7.04	0.05
140	5.0	0.0156	83.6	6.77	0.20
160	5.0	0.0187	81.7	7.17	0.37

The use of inert material like clay, garbage tankage or screenings has not proved helpful in conditioning sludge. At times it is advantageous to dilute sludge before dewatering with presses or filters.

The heating of sludge is both troublesome and expensive, and at Milwaukee very elaborate equipment has been provided for this purpose and also for conserving the heat in the filtrate from the Oliver filters by means of suitable heat exchangers. It is expected to raise the temperature of the sludge from 50° up to 140° F. by means of these exchangers. It is expected that it will not be necessary to heat sludge more than 5 months in the year.

DRYING DEWATERED SLUDGE

Activated sludge that has been dewatered to 80 to 85 per cent moisture can be dried without great difficulty to 10 per cent or less moisture content by rotary dryers of the direct or direct-indirect type, in which condition, after sizing to pass an eight-mesh sieve, it is available for fertilizer use. The type of dryer best adapted for the purpose is yet to be demonstrated. Atlas dryers of the direct-indirect type are installed at Milwaukee and Chicago, and at Houston successful results have been obtained with a Buckeye dryer of the direct-indirect type.

An Atlas dryer, 60 feet long by 8 feet in diameter, receiving activated sludge containing 80 per cent of water is expected to produce fertilizer containing 10 per cent or less of moisture at a rate of 15 to 20 tons in 24 hours of continuous service.

Suitable dust arresters (cyclones) must be provided and in many cases it is probable that air washers will be needed if nuisance from the dryer fumes is to be avoided.

With continuous operation under favorable test conditions, it is possible to secure an evaporation of 8 to 9 pounds of water per pound of coal, but this ordinarily falls off to 5 or 6 pounds or less in practice. The best method of operation usually is continuously to return a substantial portion of the dried sludge and mix it with the wet sludge, thus reducing the moisture content of the material entering the dryer.

PREPARATION AND STORAGE FOR MARKET

In drying, the sludge usually forms balls, so that it is necessary to grind it in a suitable crusher or mill. For use as a fertilizer it should be pulverized to pass an eight-mesh sieve, but it is not desirable to crush the fertilizer so fine that more than 5 to 10 per cent will pass a hundred-mesh sieve.

In disposing of sludge as a fertilizer, it must be considered that the demand fluctuates widely during the year. At the Milwaukee works, a sludge storage building is provided with some 25,000 tons capacity, to store material during the off season.

At Chicago, some sludge has been disposed of in relatively small packages (100 pounds or less) for individual use on lawns and gardens and it is possible that such use might be encouraged and a relatively better price secured.

LAGOONING AND OTHER METHODS OF DISPOSAL

At Houston, activated sludge has been disposed of for some years in both deep and shallow lagoons, in a satisfactory manner and without creation of a serious nuisance.

At the Chicago (North Side) plant it was proposed to pump the excess activated sludge through a 14-inch force main some 18 miles long and discharge it into abandoned quarries along the Drainage Canal, but this was in the nature of a temporary expedient, pending further developments in the disposal of activated sludge.

In certain arid districts it is possible to use activated sludge without dewatering as a fertilizer, as has been developed on a comparatively small scale at Jamshedpur in India. At Shanghai, it is claimed that the activated sludge from plants recently constructed can be disposed of readily to Chinese cultivators as a fertilizer. It is doubtful, however, whether these methods will have much practicable application in America.

DIGESTION OF ACTIVATED SLUDGE

Recently, considerable study has been given to the digestion of excess activated sludge with a view to reducing its volume and putting it in condition where it can be economically dewatered on sand drying beds, like sludge from two-story tanks. Experiments have been made simultaneously at Chicago (Calumet) and Essen, the Chicago work being on a larger scale. The results of investigation on this subject at Essen, Germany, are well described by Imhoff,[1] and the conclusions reached will be briefly stated.

RATE OF DIGESTION

Activated sludge by itself digests quite slowly, but if inoculated with digested sludge from a two-story tank, or if mixed with both

[1] Engineering News-Record, Vol. 94, p. 936. 1925.

fresh and digested sludge, digestion proceeds at a far more rapid rate. This is well illustrated by Fig. 43 already referred to in Chapter XXI which shows the relative rates of digestion of a given quantity of organic matter, as measured by the gas evolved, for activated sludge alone and for different mixtures of sludge.

QUANTITY OF SLUDGE PRODUCED

Imhoff estimates the quantity of sludge which would be produced from preliminary two-story tanks receiving excess activated sludge, for German city sewage from a combined system, as follows:

Nature of sludge	Liters per capita per day	Per cent water
Fresh sewage	0.6	95
Digested	0.2	80
Excess activated	2.5	98
Digested activated	0.16	80
Total digested	0.36	80

SIZE OF SLUDGE DIGESTION CHAMBERS

Owing to the rapid digestion and reduction in water content of excess activated sludge treated in two-story tanks, the increase of sludge chamber capacity required is not as great as might be expected. The Essen experiments showed that the water content of activated sludge was reduced from 98 or 99 per cent to 91 per cent in 7 days. Fig. 79 shows the progressive reduction in water content of the sludge and required sludge chamber capacity for German conditions.

The Calumet tests at Chicago, on a larger scale, show a reduction from 99 to 89 per cent moisture.

The slurry, or humus from settling tanks following trickling filters, which resembles activated sludge to a considerable extent, has been successfully digested in the preliminary two-story tanks at a number of works for some years past.

SLUDGE DIGESTION ELSEWHERE

Activated sludge has been disposed of at a number of English plants by mixing it with the sludge from preliminary settling

tanks, but in these plants the activated sludge is such a small portion of the total sludge that it is practically lost.

At Indianapolis, the excess activated sludge is being mixed with the sludge from the screen concentrate tanks and digested in large earthwork basins or tanks. Digestion apparently pro-

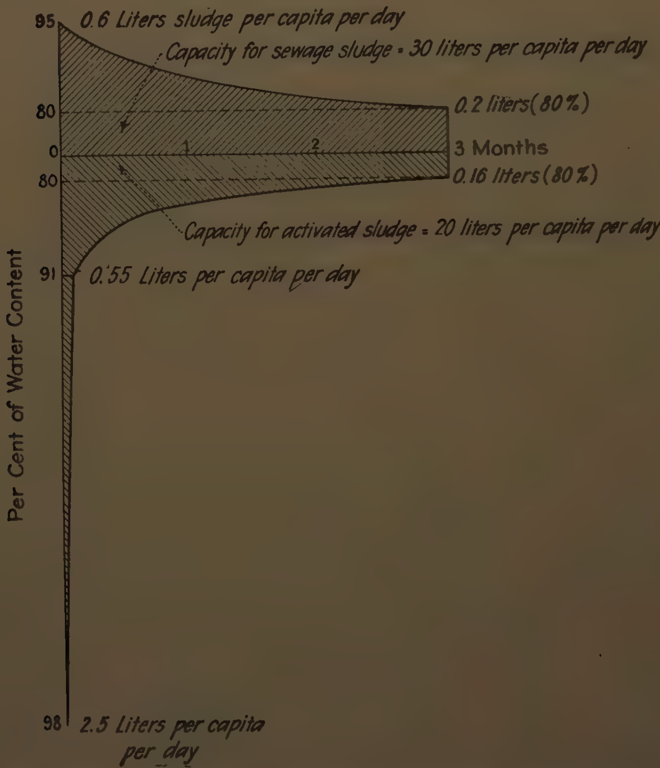


Fig. 79.—Sludge room capacity in two story tanks under conditions in Germany.

gresses as well as in the usual separate sludge digestion tanks and is not productive of nuisance.

At the new West Side Imhoff tank plant at Chicago, it is proposed to receive the excess activated sludge from the North Side plant, and capacity will be allowed in the digestion compartments for this purpose, to the extent of 5 cubic feet per capita for the North Side in addition to 2 cubic feet per capita for the Imhoff tank (West Side) sludge.

CHAPTER XL

ACTIVATED SLUDGE AS A FERTILIZER

SYNOPSIS

1. Plant Food.—Dried activated sludge contains from two to four times as much organic nitrogen as any other sludge excepting the slurry obtained from final tanks following coarse grained filters. This nitrogen content of 4 to 7.6 per cent is due to the absence of sludge digestion and to the supplementing of the constituents of sludge from ordinary sedimentation by the addition of the so-called non-settleable solids and colloids removed from the sewage by the activated sludge process. The dried sludge is free from bad odors.

2. Relation to Fertilizer Trade.—Suitably dried activated sludge is a good fertilizer for many purposes, but it is not a complete commercial fertilizer owing to deficiencies in phosphoric acid and potash. When these ingredients are added it is comparable with commercial fertilizers.

3. Field Tests.—Numerous tests in various parts of the world show that activated sludge produces good results as a fertilizer for lawns, greenhouses and farm products, as shown by the reports from Milwaukee and elsewhere.

4. Economic Aspects.—For small cities and for others favorably located for disposing of their sludge in other ways the fertilizer market does not offer financial profit. But for some places, as at Milwaukee, this is not the only criterion and it must be compared with other arrangements as to net cost. Obviously it is advantageous to make plain its benefits so as to create a local market and avoid the expense of long hauls to the consumers.

QUALITY OF SLUDGE PRODUCED

Practically from the inception of the process, the high nitrogen content of activated sludge focused attention on its availability as a fertilizer. In a general way, this sludge contains two to four times as much nitrogen as any other type of sludge except perhaps

the humus sludge from trickling filter effluents. Typical analyses in Table 75 show the character of dewatered activated sludge.

TABLE 75.—CHARACTERISTICS OF DEWATERED ACTIVATED SLUDGE

	Per Cent
Moisture	6.20
Milwaukee	
Total nitrogen as ammonia	7.42
Water-soluble nitrogen as ammonia	1.13
Active water-insoluble organic nitrogen as ammonia (alkaline permanganate method)	4.17
Availability of water-insoluble organic nitrogen	66.35
Total availability of nitrogen	71.48
Total phosphoric acid	2.36
Potash (water-soluble)	0.13
Fat	4.87
Houston	
Moisture	5.75
Total nitrogen as ammonia	4.36
Available phosphoric acid	1.97
Potash	0.22
Manchester (*Withington*)	
Loss on ignition	75.2
Total nitrogen (N)	6.4
Phosphoric acid	3.8
Sanitary District of Chicago	
Des Plaines Treatment Works	
Total nitrogen (N)	5.0 to 5.5
Phosphoric acid (P_2O_5)	3 to 4
Calumet Treatment Works	
Total nitrogen (N)	4.2 to 4.4
Packingtown Testing Station	
Total nitrogen (N)	4.2
Phosphoric acid (P_2O_5)	2.7
Argo Testing Station (Corn Products Wastes)	
Total nitrogen (N)	7 to 8
Phosphoric acid (P_2O_5)	6 to 7
Sludge from Tannery Wastes	
Total nitrogen (N)	3.0

NOTE.—Nitrogen (N) is 82 per cent of nitrogen as ammonia.

WORK OF MILWAUKEE SEWERAGE COMMISSION

The most important work, following the earlier studies of Bartow, in developing the use of activated sludge as a fertilizer has been done by the Milwaukee Sewerage Commission. The Milwaukee plant was equipped in a very elaborate manner for the production of dried activated sludge in suitable form for fertilizer use and is designed to turn out 100 tons of this material

daily. Realizing the necessity of having a market for this product, the Commission in 1923 established a fellowship in the College of Agriculture, University of Wisconsin, for the sole study of activated sludge as a fertilizer. They have also strongly endeavored to encourage the use of the material, as far as possible, locally, in view of the fact that the rather low nitrogen content of the sludge limits the economic shipping range. The results of their work will be briefly summarized.

FIELD EXPERIMENTS

Numerous comparative plantings of rye, potatoes and corn on different Wisconsin farms using sludge mixtures reinforced with

Fig. 80.—Potato yield.

Fertilizer, 900 Pounds Per Acre	Yield in Bushels per Acre
No fertilizer	111.3
4–10–6 sludge	168.2
4–10–6 tankage, etc	170.2

phosphoric acid and potash, so as to be equivalent to various commercial mixtures and with equal amounts of nitrogen, have been made. The yields were in general quite as good from the sludge plots as from the others and in certain cases somewhat better. It is evidently very well demonstrated both by greenhouse and field experiments that the nitrogen in activated sludge is highly available for plant growth (See Fig. 80).

GREENHOUSE EXPERIMENTS

Experiments made by planting corn and oats in soils mixed with activated sludge demonstrated that a large part of the nitrogen in the sludge becomes available in 2 months. In a comparative series of tests with Sudan grass on the availability of the sludge, it was found that four- to eight-mesh material was practically as effective as ten-mesh and one-hundred-mesh

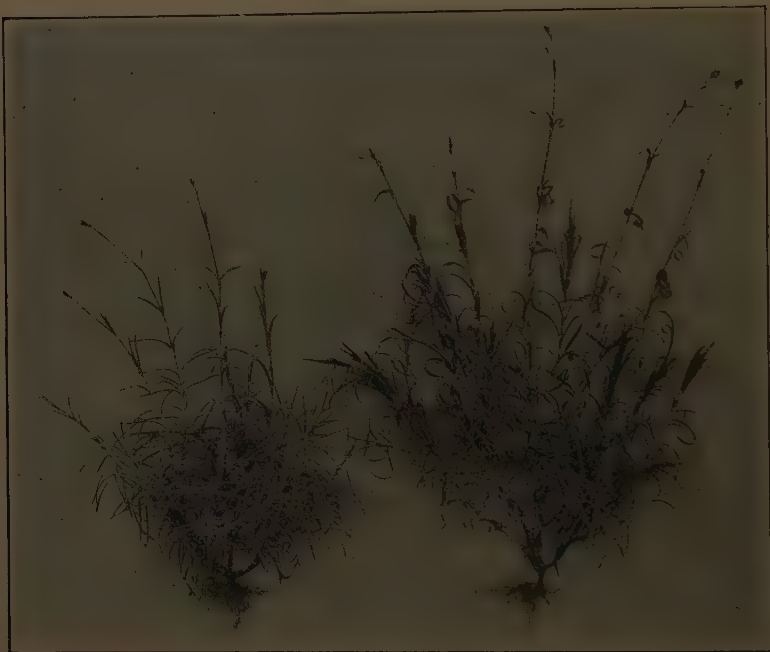


FIG. 81.—Typical carnation plants.
Left—no treatment.
Right—fertilized with activated sludge and acid phosphate.

material. Numerous comparative studies of the sludge with sheep manure, tankage, dried blood, fish scrap and cotton-seed meal were made, the sludge being applied at the rate of 1000 pounds per acre and the other materials to give equivalent amounts of nitrogen. Essential elements other than nitrogen were added in soluble form to bring the various materials to a parity in all cases. The sludge produced decidedly better growth than sheep manure and very nearly as good growth as the other materials. (See Figs. 81 and 82.)

LAWNS AND GOLF COURSES

Activated sludge has proved to be an excellent fertilizer for lawns and is even superior to sheep manure which is largely used

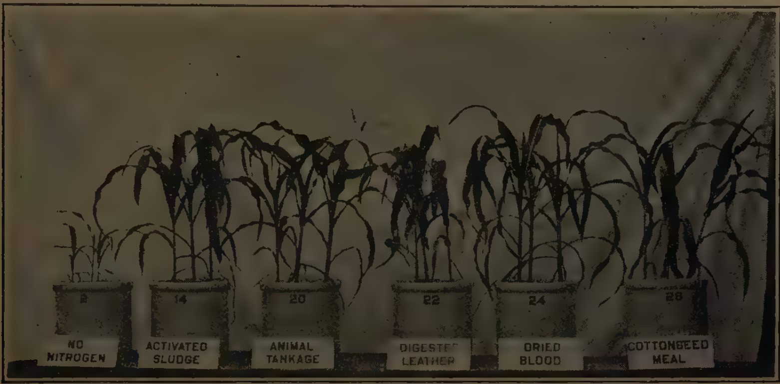


FIG. 82.—Corn in quartz cultures in greenhouse trials.

Each jar received 0.42 gram nitrogen from sources indicated. Other essential elements supplied in soluble form and soil suspension to provide necessary bacterial flora.

FIG. 83.—Fairway, Milwaukee Country Club.

Area to right received 2000 pounds per acre of a 5–6–4 sludge mixture prior to seeding. Area to left received no fertilizer.

for this purpose. As a lawn fertilizer it has two advantages: there is no danger of burning the grass even with many applications, and no objectionable odors develop when the lawn is sprinkled after sludge has been applied.

The sludge has been used successfully on a number of golf courses both on greens and on the turf nursery. Ammonium sulphate in solution is quite commonly used on golf greens, although there is always danger of burning the grass, and the effect is only temporary, due to the leaching out of the chemical. A mixture of sludge and ammonium sulphate is perfectly safe and "foolproof," is cheaper, and makes an ideal combination, inasmuch as the ammonium sulphate provides the initial stimulant, while the sludge furnishes humus and a continuing source of plant food long after the effect of the ammonium sulphate has disappeared (See Fig. 83).

IRRIGATING WITH ACTIVATED SLUDGE

The use of activated sludge without dewatering for combined irrigating and fertilizing purposes would seem to have considerable merit under certain conditions. Professor Gilbert J. Fowler, writing of conditions in India, states as follows:

"By the adoption of the activated sludge process as a preliminary to land treatment, it has been demonstrated that sewage farms may be established without nuisance and with the least loss of the manurial value of the water-borne sludge."

As the volume of activated sludge is only 1 to 5 per cent of the sewage, the difficulties of caring for the entire flow, when water is not needed by crops,—one of the drawbacks to sewage farming,—would be very much minimized.

MANCHESTER EXPERIMENTS

An interesting experiment on spring wheat at Manchester, England, is reported by Ardern. Fifteen plots, each of 108 square yards area, were sown; three control plots were without manure; six were treated with sulphate of ammonia, three equivalent to 40 pounds per acre and three to 80 pounds per acre; while the remaining six plots were manured with activated sludge so that the nitrogen added was equal to that contained in the sulphate of ammonia. The results are recorded in Table 76.

It will be seen that on the average the addition of the sludge doubled the weight of grain produced, and further that the fertilizer value equaled that of the nitrogen in the form of sulphate of ammonia, or, in other words, the nitrogen in the sludge is readily available for plant nutrition.

TABLE 76.—MANCHESTER EXPERIMENTS WITH ACTIVATED SLUDGE AS FERTILIZER

Treatment	Grain		Straw	
	Total pounds	Bushels per acre	Total hundred weights	Per acre hundred weights
Control	46	11.5	2¼	34
Ammonium sulphate, 40 pounds N per acre	96	24.0	2¾	41
Activated sludge, 40 pounds N per acre	89	22.2	2½	38
Ammonium sulphate, 80 pounds N per arce	96	24.0	3	45
Activated sludge, 80 pounds N per acre	108	27.0	2¾	41

EXPERIMENTS AT HOUSTON

At Houston numerous tests with activated sludge as a fertilizer have been made and Table 77 shows typical results in growing turnips.

TABLE 77.—HOUSTON EXPERIMENTS

	Weights tops, ounces	Weights roots, ounces	Total weight, ounces	Per cent increase, roots	Per cent increase, total
Not fertilized	8	3	11	0	0
Dried blood	11	7	18	133	64
Nitrate of soda	27	14	41	367	273
Activated sludge	35	28	63	832	473
Activated sludge and phosphoric acid	28	31	59	932	436

The seed was planted March 9 and harvested June 6, 1922, growing under identical conditions; the amount of fertilizer used was equivalent to 80 pounds of nitrogen per acre in all cases. A mixture containing 3 per cent nitrogen and 7 per cent phosphoric acid was used in the last item. The turnips fertilized with activated sludge were the only ones edible, being sound and sweet, the others being dry and fibrous.

PRESENT STATUS OF SLUDGE AS FERTILIZER

The following extracts from the Report of the Committee on Sewage Sludge, American Public Health Association, made in

October, 1925, outline well the progress and present status of activated sludge as a fertilizer:

Increased interest has been shown in the use of sewage sludge on the part of the agriculturist and fruit grower. Remarkable demand has appeared upon the part of golf clubs, flower growers and fertilizer manufacturers for the organic nitrogen in the sludge when reduced to a dry basis so that it can be properly handled. Activated sludge, when properly prepared by drying and grinding, is sought by many different types of users. The Milwaukee Sewerage Commission, with the cooperation of the Sanitary District of Chicago, has, for the past two seasons, distributed prepared activated sludge, free of cost, for trial to many golf clubs in the Detroit, Cleveland, St. Louis, Minneapolis and Milwaukee districts—57 in all. In the majority of cases, the clubs have tried to get sufficient sludge this year for their fertilizing needs, but little being available, their requests could not be complied with. The Milwaukee Sewerage Commission has also distributed to many flower growers in Illinois, Michigan and Wisconsin the prepared sludge with the result that a very considerable tonnage has been requested by this type of user. For 18 months truckers in large numbers have been attempting to secure activated sludge without success, because it has not been manufactured in sufficient quantity. The investigations so far conducted on the fertilizer value of activated sludge have been broad and have embraced the feeding of many types of ground-growing staple crops, such as corn, tobacco, potatoes, tomatoes and cereals. In most cases, the several types of ground and crops have satisfactorily responded. For the growing of lawn and bent grass it has been especially successful. It proves better than sodium nitrate in that a surplus does not burn the grass and there is a very decided residual value in the sludge which is not in the nitrate. It is better than manure in that the plant food is more concentrated and contains no harmful seed to inoculate the soil or injure the grass. The best market, however, is with the fertilizer manufacturer who uses it as a filler to supply the organic nitrogen needed in the best complete mixtures. Synthetic and mineral nitrogen are great plant foods, but are not equal to organic nitrogen which has for years been largely supplied by the packing house industry in the form of tankage and which, since the war, has been converted largely into livestock food.

The production of activated sludge to date has been very small and has been practically confined to the Calumet and Maywood sewage works of the Sanitary District of Chicago and to the plant of the city of Houston, Tex. These plants have produced approximately 40 to 50 tons per month, although not continuously. The city of Houston has sold some of its sludge for $12 per ton f.o.b. cars at the sewage works. The Sanitary District of Chicago has received for its sludge in 100-pound bags $22.50 per ton f.o.b. cars near works.

RESUME

On the whole, it appears that activated sludge, when properly dewatered and put in suitable condition for the market, is a good fertilizer material for many purposes, or rather that it is an excellent fertilizer base. The fact must not be lost sight of that it is not a complete fertilizer, but requires the addition of other ingredients, notably phosphoric acid and potash, in order to place it upon a comparable basis with commercial fertilizers.

The advantages of so handling activated sludge, however, are that it is shipped away from the point of production, usually in thickly settled areas; objectionable organic solids are kept out of nearby watercourses; and products are returned to the soil where they are once more made available for plant life.

To produce it in shape for use as a fertilizer requires a complicated and expensive plant and the cost of production is very considerable. Furthermore, its fertilizing value is not high enough, under ordinary conditions at least, to warrant its shipment to very great distances from the point of origin.

Both the market price and the demand for fertilizer materials fluctuate widely, whereas the production of sludge at any sewage treatment plant continues practically uniform and costs the same from day to day.

In order to market it successfully it will be necessary to demonstrate thoroughly its value not only to the fertilizer trade, but also to the ultimate consumer, the farmer, and at the same time its price must always be maintained low enough to insure its being taken away.

It is hoped that it may ultimately come into wide use to the benefit of agriculture as well as the communities producing sludge. The present outlook, however, is, except in the case of certain large cities which are favorably situated, that it may cost more to dispose of sludge as a fertilizer than by other means.

CHAPTER XLI

NON-TECHNICAL SUMMARY

Extent of Problem.—During the past generation, the population of incorporated municipalities in the United States, which pollute our rivers, lakes and coastal waters has increased about 40,000,000. Industries, streets and roads may now contribute at times as much more pollution.

Less than 10 per cent of this polluting material is treated to improve its quality. This means that during the past generation pollution from the equivalent of an additional population of more than 50,000,000 persons has become a further burden on our water ways.

Already many of our water courses are polluted to a dangerous extent from the public health standpoint. They are offensive to sight and smell. Fish life has been interfered with.

The American water courses will never increase in size or in capacity to absorb filth. The margin of remaining capacity is disappearing so rapidly as to be the cause of genuine alarm. Our country is about to experience the difficulties found 50 to 75 years ago in the more populated sections of Europe.

The different aspects which sewage problems present and the different ways of treating each of them have been outlined in the preceding chapters. Their variety and interrelations resemble somewhat in scope the human ills the physician is called upon to treat. He has no universal panacea. Neither has the engineer for sewage problems. Often the advice of the physician will be based in part on the circumstances of the patient. It will be different for the laborer on small wages and the wealthy person able to give all his time and unlimited money to the task of recovering his health. The engineer also has to adjust his recommendation and program to the conditions of each sewage problem.

It must be kept in mind that from four to twelve or more years frequently elapse between the date when sizeable improvements are first recommended by public officials and the date of their completion. This long intervening period seems necessary

under average American conditions to overcome public inertia in approving and executing sewage improvements. Hence they are particularly important for early consideration by civic authorities and by public-spirited citizens who take an active interest in public health and welfare.

Comprehensive Planning.—Experience shows the wisdom of planning far ahead and adopting a comprehensive program. Then, occasionally, the plan should be reviewed, to make sure that it is kept abreast of the progress in the art of sewage treatment. The public official must also consider, so far as he can, the probable industrial growth of his community as well as its increase in population. A considerable part of the troublesome sewage problems are due to the discharge of trade wastes into sewers or directly into bodies of water. In the Sanitary District of Chicago these industrial wastes are equivalent to the sewage of 1,600,000 persons, approximately half the population of the district. Every city desires to encourage industries to grow in and about it, but in voicing and extending this encouragement the prudent public official will try to safeguard the taxpayers against the needless expense of treating some kinds of wastes which mill owners should separate at their plants, so that relatively clean water will go directly to the water courses while the polluting wastes will go to the sewers in accordance with suitable regulations.

Choice of Treatment Methods.—The choice of a method of treatment for a given set of local conditions depends upon the relative efficiency and cost of different types of plants and on various local factors. One important factor is the practicability of adopting early a comprehensive program, so that the works may be built progressively as the need for them arises and funds are available. The efficiencies of the several major processes in removing objectionable properties of raw sewage are set forth in the respective chapters dealing with those processes.

Engineers know well that construction costs vary widely with the different local prices of labor and materials and the circumstances surrounding construction work. Attempts to use the cost data of one city as a guide in making estimates of cost for another city are likely to result in misleading figures. In spite of the difficulties of giving such data, city officials always ask for comparative information as to the general advisability of one or another treatment method.

Sewage Solids Must Go.—Generally speaking, the day is not far distant when the great majority of cities and towns will have to take steps toward removing settleable solids as well as floating matter from their sewage. This means that some type of sedimentation tank should be provided, becaue fine screens will not remove sufficient solid matters to meet the ultimate requirements in many localities.

Tanks or Screens.—Sedimentation tanks usually cost fully double as much as fine screens, but they effect the removal of four to six times as much of the settleable solids. Hence, by reducing the size of settling tanks until their cost will be equal to that of a fine screen plant, they will remove more solids than will the equally expensive screens. Fine screens are appropriate for some congested water fronts adjacent to or near large, deep waterways. They no longer seem so generally suitable as they did before the recent advances in tank treatment. Reference is here made to the practicability of pumping sludge from sedimentation tanks in built-up areas to separate digestion tanks in isolated areas, and to the procedure of collecting and burning or selling the gases of decomposition from such tanks.

The size of sedimentation tanks for a given population depends upon the period of settling and this in turn is related to the volume of sewage per capita. Exclusive of land, conduits and pumping, the cost of sedimentation tanks has been variously estimated at $3.50 to $7.00 per capita.

Under most circumstances the adoption of some form of sedimentation tank is the best way to prevent the accumulation of sewage solids in water courses. Existing deposits of putrefying sewage solids can only be removed by dredging, a much more expensive procedure than removal by tanks.

Further Treatment of Settled Sewage.—When the water available for dilution is insufficient to prevent putrefaction of the settled sewage turned into it, some form of oxidizing treatment is required to prepare the tank effluent for dilution. This makes the investment for the complete plant about two to three times the ranges given for sedimentation tanks, depending upon the volume of sewage per capita, the presence of trade wastes and the method of sludge disposal. The activated sludge process is cheaper to install, as a rule, than a trickling or other type of filter. Operating costs of the filters are less, however, which tends to offset their greater capital charges.

With the advent of methods now available and understood for controlling odors and flies, the task of acquiring suitable sites for trickling filters as well as tanks is less difficult than formerly. Nevertheless the activated sludge method requires a smaller area of ground, with relatively little isolation, in comparison with trickling filters. All those factors of particular local significance, such as land, length of conduits and necessity for pumping, should be investigated for each project, so as to establish a sound comprehensive program. Such a program should be adopted early so that for a term of years all construction may proceed in a coordinated way, thus avoiding waste by having to abandon, supplement or adjust works inadequately designed for future use.

Chlorination needs no comment here as it is dealt with adequately in Chapter XXIX.

Faithful Operators Needed.—A sewage treatment plant resembles in many ways a manufacturing plant; its product is an effluent, or treated sewage, having definitely fixed limitations of quality. Each part of the plant is designed for doing in the best way a certain kind of work, and there is often just as much technical difference between these kinds of work as there is between the work of different departments of a manufacturing plant. With incompetent management, if any part functions poorly, the other parts will be overloaded in an attempt to get results from them which they were not designed to give.

A well operated sewage treatment plant, built along the lines described in this volume, will give consistently good results, whereas a poorly operated sewage treatment plant, no matter how well designed, generally gives consistently unsatisfactory results. Consequently the taxpayer obtains little or no return from the investment in the installation of the plant, and the nuisances which it was sought to remedy continue unabated. In all countries engineers find that the operation of sewage treatment plants is good or bad depending upon whether there is an operating force which will faithfully carry out suitably prepared instructions. It is this criterion of faithfulness which should be kept in mind in examining practical accomplishments in this field of sanitation.

Unfortunately there are many of the smaller sewage treatment plants in this country so neglected that they may be said to be practically abandoned. The larger cities ordinarily provide a suitable operating personnel and install a laboratory at the plants,

whereby data may be secured which, in connection with other records, will establish the actual accomplishments of the treatment plant. Such records are well worth their cost, through their direct benefit in aiding the abatement of the nuisances which led to the construction of the plant, and indirectly, in some cases, in guarding against suits for pollution of water courses which receive the wastes from a number of other sources.

State Supervision of Operation.—It is because of the prevailing poor operation of smaller sewage treatment works that certain States have considered forcing the municipalities to operate their plants properly. In fact, New Jersey has a law requiring all such operators to be licensed, and in several other States operators are examined to see if their experience qualifies them to be plant operators. Texas, Pennsylvania, New Jersey and some other States are also attempting to accomplish the same thing by short-term schools for such operators.

Competent operators will be able, if moderately encouraged and given sufficient funds for operation, to improve the performance and appearance of sewage treatment plants. For many years street cleaning was considered the most menial part of public works in New York. When Colonel Waring was put in charge of it, he soon showed everybody that he was proud of his job, and he so imbued the entire force under him with his own feeling that it became the rival of the police and firemen in snappy work. Sewage treatment plants need management of the same kind. A well-operated plant is so important to the community that it should be a source of pride to the taxpayers. It will be if the plant and its surroundings are put in good order and maintained so as to give an attractive appearance. To promote such an end should be the endeavor of administrative municipal authorities and of those civic organizations whose activities prompt them to keep a watchful eye over municipal undertakings related closely to public health and welfare.

APPENDIX A

PROCEDURES FOR CONTROLLING WASTES

Discussion of administrative aspects in Chapter III shows that the trend of the times is strongly toward the control of these problems, first by regional or major districts as against the artificial boundaries or political subdivisions of countries or states and secondly by more efficient and workable relations between industries and administrative authorities. Without further comment we cite for convenience several references to procedures which have been taken in the direction of improved control.

PASSAIC VALLEY SEWERAGE DISTRICT ACT

In preparing the maps, plans and specifications for the intercepting sewer or sewers, plant or works, to be made by the said commissioners as herein provided, and in making the estimate of the sewage capacity required for each municipality, regard shall be had by the said commissioners both to the area and population to be provided for, making provision, however, for not more than ten per centum of the factory waste and excluding all waste from gas works, and all substances or discharges which may injuriously affect the integrity of the sewer or sewers when constructed.

Chapter 10, N. J. Laws of 1907.

MILWAUKEE SEWERAGE COMMISSION

The commission shall have authority whenever it shall deem it necessary to act or proceed in any manner whatsoever relating to the powers and duties under this act by or through any other department of such city; when the commission shall make written requests of any such department for the performance of any such act or acts it shall be the duty of such department, thereupon, to act as required, provided that the act or acts required to be done have reference to the powers and duties of such department.

If any differences shall arise between such commission and any of the other departments in any such city in the discharge of their respective powers and duties, the ruling of the commission shall be advisory and the ruling of the common council shall be supreme and final.

Section 11, Chapter 608, Wisconsin Laws of 1913.

OHIO LAW TO CONTROL STREAM POLLUTION

Section 1. That section 1240 of the General Code be amended and that such amended section be supplemented by enactment of supplemental sections 1240–1, 1240–2 and 1240–3 to read as follows:

Section 1240. No city, village, county, public institution, corporation or officer or employe thereof or other person shall provide or install a water supply or sewerage, or purification or treatment works for water supply or sewage disposal, or make a change in any water supply, water works intake, water purification works, sewerage or sewage treatment works until the plans therefore have been submitted to and approved by the state department of health. This act shall apply to water supply, sewerage, and purification or treatment works for water or sewage of a municipality or part thereof, an unincorporated community, a county sewer district or other land outside of a municipal corporation or any publicly or privately owned building or group of buildings or place, used for the assemblage, entertainment, recreation, education, correction, hospitalization, housing or employment of persons, but shall not apply to water supply or sewerage or purification or treatment works for water or sewage installed or to be installed for the use of a private residence or dwelling, or to water supply for industrial purposes and not intended for human consumption. In granting an approval authorized by this section the state department of health may stipulate such modifications, conditions and regulations as the public health may require. Any action taken by the director of health shall be a matter of public record and shall be entered in his journal. Whoever violates any provision of this section shall upon conviction thereof, be fined not less than one hundred dollars nor more than five hundred dollars for each offense, and a separate offense shall be deemed to have been committed for each period of thirty days such violation shall continue after such conviction.

Section 1240-1. No city, village, county, public institution, corporation or officer or employe thereof or other person shall establish as proprietor, agent, employe, lessee, or tenant, any garbage disposal plant, shop, factory, mill, industrial establishment, process, trade or business, in the operation of which an industrial waste is produced, or make a change in or enlargment of a garbage disposal plant, shop, factory, mill, industrial establishment, process, trade or business, whereby an industrial waste is produced or materially increased or changed in character, or install works for the treatment or disposal of any such waste until the plans for the disposal of such waste have been submitted to and approved by the state department of health.

For the purposes of this act industrial waste shall be construed to mean a water-carried or a liquid waste resulting from any process of industry, manufacture, trade or business, or development of any natural resource. In granting an approval authorized by this section the state department of health may stipulate such modifications, conditions and regulations as the public health may require. The state department of health shall not exercise any authority under the provisions of this section in any municipal corporation wherein ordinances or resolutions have been adopted and are being enforced by the proper authorities to make effective the provisions of this section. Any action taken by the director of health shall be a matter of

public record and shall be entered in his journal. Whoever violates any provision of this section shall upon conviction thereof be fined not less than one hundred dollars nor more than five hundred dollars for each offense and a separate offense shall be deemed to have been committed for each period of thirty days such violation shall continue after such conviction.

Section 1240–2. The state department of health should exercise general supervision of the disposal of sewage and industrial wastes and the operation and maintenance of works or means installed for the collection, treatment or disposal of sewage and industrial wastes. Such general supervision shall apply to all features of construction, operation and maintenance of such works or means which do or may affect the proper treatment or disposal of such sewage and industrial wastes. For the purpose of exercising such general supervision the state department of health shall investigate the works or means employed in the collection, treatment and disposal of sewage and industrial wastes whenever deemed necessary by the department and whenever requested to do so by local health officials; and may adopt and enforce orders and regulations governing the operation and maintenance of such works or means and may require the submission of records and data of construction, operation and maintenance, including plans and descriptions of existing works or means of disposal of such sewage or wastes. When the state department of health shall require the submission of such records or information the public officials or person, firm or corporation having the works in charge shall promptly comply with such order.

Section 1240–3. The state department of health shall study and investigate the streams, lakes and other bodies of water of the state and waters forming the boundaries thereof, for the purpose of determining the uses of such waters, the causes contributing to their pollution and the effects of the same, and the practicability of preventing and correcting their pollution and of maintaining such streams, lakes and other bodies of water in such condition as to prevent damage to public health and welfare. For the purpose of providing effective control of the discharge of sewage and industrial wastes into the various streams, lakes and other bodies of water and for preventing the undue pollution thereof, the state department of health may adopt and enforce such special or general regulations as it may deem necessary for the protection of the public health and welfare.

Section 2. That original section 1240 of the General Code be, and the same is hereby repealed.

Approved March 19, 1925.

INTERSTATE STREAM CONSERVATION AGREEMENT OF PENNSYLVANIA, OHIO AND WEST VIRGINIA

Whereas the Beaver, the Monongahela, and the Ohio Rivers are used as the only available sources of public water supply by many municipali-

ties in Ohio, Pennsylvania and West Virginia; and such use must of necessity increase with the future increase of population; and

Whereas the protection and promotion of the public health demand that the water of these streams shall be suitable to permit the production of safe, wholesome, and palatable water supplies, after reasonable purification; and

Whereas sewage and industrial wastes are now discharged to the said rivers and many of their tributaries to an extent affecting the safety, wholesomeness, or palatability of water supplies obtained therefrom; and future increase in the pollution of these streams will occur unless suitable corrective and preventive measures are applied; and

Whereas the said rivers and many of their tributaries are interstate streams common to Ohio, Pennsylvania, and West Virginia, and pollution thereof originating in one State does or may prejudicially affect public water supplies, public health, or public interests in the neighboring State, thus creating a problem of common interest and requiring cooperation between the three States: Therefore be it

Resolved, That the departments of health of Pennsylvania, Ohio and West Virginia, represented, respectively, by the secretary of health of the department of health of Pennsylvania, the director of health of Ohio, and the health commissioner of West Virginia, hereby agree to cooperate in carrying out a policy for the conservation of the interstate streams in these States, including the correction and prevention of the undue pollution thereof, to the end that the said streams may be rendered and maintained as suitable sources of public water supplies as aforesaid.

CORPORATION ACT, 1915, COUNTY BOROUGH OF DEWSBURY, ENGLAND, DISPOSAL OF TRADE REFUSE

Regulations with respect to the disposal of trade refuse made by the Mayor, Aldermen and Burgesses of the County Borough of Dewsbury on the ....th day of .... in pursuance of the provisions of the Dewsbury Corporation Act 1915 and of every other power in that behalf them enabling.

1. Interpretation.—"The Act of 1915" means the Dewsbury Corporation Act, 1915.

"The Borough Engineer" means the Borough Engineer for the time being of the Corporation.

"Clean Waters" means the surface and other waters the subject of the provisions of No. 2 of these Regulations.

"Trade Refuse" means Trade Refuse as defined by the Act of 1915 other than clean waters.

"Surface Water Sewers" means Sewers the contents from which are not directly or indirectly discharged into Sewage Outfall Works.

"Sewers" means Sewers other than surface water sewers.

Other words and expressions to which meanings are assigned by the Act of 1915 shall have in these Regulations the same respective meanings unless there be something in the subject or context repugnant to such construction.

2. Exclusion from Sewers of Surface and Other Waters.—The Trader shall exclude from the trade refuse discharged from his trade premises and from any sewers of the Corporation all surface and condensing water, springs of water, the overflows from reservoirs of such water and all water used in or for the purposes of his trade which after being so used is not poisonous, noxious or polluting within the meaning of the Rivers Pollution Prevention Act 1876 and shall cause all the said waters to be discharged from his trade premises into some proper and efficient outlet other than the sewers of the Corporation and for this purpose he shall where necessary provide and maintain at his own cost a separate system of drainage from his trade premises. Provided however that the trader shall be permitted to discharge the said waters so to be excluded as aforesaid into any existing surface water sewers of the Corporation.

3. Trade Refuse Not to Be Discharged into Surface Water Sewers.—The Trader in no case shall discharge any trade refuse into any surface water sewer, except as provided in Clause 2.

4. Provision of Tanks for Settlement.—The Trader shall provide and maintain on his trade premises settling tanks of such design and capacity as will enable the requirements of the Regulations next hereinafter contained to be complied with. Such tanks shall be fitted with a suitable and adequate screen or screens for keeping back fibrous matter.

5. Treatment for Solids.—The Trader shall so far as is reasonably practicable cause the solid matter to be removed from the trade refuse from his trade premises before it is discharged into the sewers of the Corporation, and where such removal can only be adequately secured by precipitation he shall also cause the said trade refuse to be treated by such chemical means as shall be necessary to secure such precipitation.

6. Fuller's Earth to Be Excluded from Sewers.—Fuller's earth shall in all cases be excluded from the sewers of the Corporation.

7. Treatment for Grease.—In any case where grease shall form part of the trade refuse from any trade premises the trader shall provide before such trade refuse is discharged into the sewers of the Corporation for the separation therefrom of the said grease.

8. Removal of Fiber Solids and Grease.—The Trader shall not discharge into the sewers of the Corporation but shall remove as frequently as may be necessary from the said tanks all fibrous and solid matter and grease which from time to time shall be deposited, precipitated or accumulated therein.

9. Regulation of Flow.—The Trader shall so far as is reasonably practicable provide for and cause the discharge of the trade refuse from his trade premises to be continuous and at an uniform and regular rate throughout the working hours of each working day (including overtime).

10. Corporation to Be Notified of Volume of Trade Refuse.—The Trader shall from time to time give notice in writing to the Corporation of any material alteration of the volume or character of trade refuse to be discharged from his trade premises.

11. Inspection Manhole.—The Trader shall provide a suitable manhole or inspection chamber on the line of the drain discharging the trade refuse from his trade premises at or near to the outlet of such drain into the sewer of the Corporation or in some other suitable position.

12. Access.—The Trader shall permit any duly authorized officer of the Corporation to enter the trade premises at all reasonable hours of the day or night for the purpose of the inspection of any apparatus provided pursuant to these Regulations or of any treatment or other operation prescribed thereby or of taking samples of trade refuse or of clean waters or otherwise.

13. Submission of Plans.—Any Trader proposing to require the Corporation to receive and dispose of trade refuse and/or clean waters or intending to discharge trade refuse and/or clean waters into a sewer by any drain not used for such purpose at the date of the passing of the Act of 1915 or proposing to enlarge or alter any drain used for the purpose of discharging trade refuses and/or clean waters into a sewer shall together with the notice required to be served by him upon the Corporation pursuant to Subsection 2 of Section 42 of the Act of 1915 give notice of the volume of trade refuse and/or clean waters respectively to be dealt with on his trade premises and deposits with the Corporation plans and sections in duplicate of the tanks and manhole or inspection chamber intended to be provided by him in pursuance of the requirements of these Regulations and also of the drains intended to be used by him and of any works connected therewith whether constructed or to be constructed and whether for the purpose of the trade refuse and/or clean waters to be discharged from his trade premises into the sewers of the Corporation or of the clean waters to be excluded and discharged as provided by No. 2 of these Regulations. The said plans shall in the case of the said tanks and the said manhole or inspection chamber be drawn to a scale of not less than 8 feet to an inch and the said drains and any works connected therewith shall be shown on a plan which shall include a group plan of the whole of the trade premises and be drawn to a scale of not less than 20 feet to an inch.

14. Interference with Streets.—All work of opening out any street including the footway thereof required for the purpose of laying or maintaining any drain to be used by the Trader under the provisions of the Act of 1915 or of these Regulations and all work of restoring and making good such street together with the work of connecting any such drain with the sewer or surface water sewer of the Corporation as the case may be shall be executed by the Corporation at the expense of the Trader and the Trader shall pay any such expense to the Corporation on demand including 5 per cent thereon for supervision and interest on all accounts not paid within one month after demand calculated at the rate of 5 per cent per annum.

15. Payment to Be Made.—(1) Any Trader who shall enter into an Agreement as hereinafter in this Regulation provided shall be entitled to avail himself of the provisions of No. 16 of these Regulations upon the terms of paying to the Corporation annually in respect of the reception and disposal of his trade refuse and/or clean waters the sum or sums of money next hereinafter provided, that is to say:

For each and every 1000 gallons of trade refuse discharged by him in pursuance of the said provisions (*a*) from which all fibrous and solid matter and grease shall not have been removed, 4d.; (*b*) from which all fibrous and solid matter and grease shall have been removed and/or clean water, 2d.

(2) The said Agreement shall provide as follows:

(a) For the payment by the Trader to the Corporation quarterly on the four usual quarter days each year of the payments to be made by him aforesaid and for such payment to be in respect of a minimum volume each year of trade refuse and/or clean waters. Such minimum quantity to be the quantity for the time being specified in the Schedule mentioned in the paragraph (b) next following, or if in any case there be no quantity specified in the said Schedule, then such minimum quantity to be such quantity as shall be either agreed between the Trader and the Corporation, or failing such agreement as shall be settled by the Committee to be appointed as provided in No. 16 of these Regulations.

(b) The said Schedule shall be the Schedule prepared and signed by William Medley (of the firm of M. Oldroyd & Sons, Ltd.) on behalf of the Traders, and Henry Dearden on behalf of the Corporation, and bearing even date with these Regulations and setting out the quantity of the normal discharge per annum of trade refuse and/or clean waters from the several trade premises in the Borough, and such Schedule shall be revised and amended from time to time by the Borough Engineer and the Chairman for the time being of the West Riding of Yorkshire Millowners' and Occupiers' Association as occasion may require (but so that no volume as therein specified shall be altered oftener than once in any period of 12 months) so as to be as far as possible a complete and up-to-date record of the matters therein stated.

(c) For the Trader or the Corporation to obtain a review of the price to be paid by the Trader under 15 (1) of these Regulations at any time after the Corporation have been treating for a period of twelve months the trade refuse from those Traders who shall within three months after the date upon which the Corporation works are ready to receive and treat such trade refuse have obtained access to the sewers of the Corporation under the provisions of these Regulations by either party giving to the other six calendar months' notice in writing.

(d) For any differences or questions which may arise between the Trader and the Corporation under or by reason of the Regulations, including any differences or questions under the Agreement to be settled by the before-mentioned Committee.

16. In any case where he shall be unable or able only at an unreasonable cost to comply with the requirements of these Regulations the Trader (subject to the provisions of these Regulations) shall be entitled to and shall discharge the trade refuse and/or clean waters as the case may be from his trade premises into the sewers of the Corporation without, as the case may be, exclusion of clean waters and/or any treatment by settlement or precipitation of solid matter or separation of grease and/or regulation of flow as prescribed by these Regulations and in any or either of such cases or where there shall be exceptional circumstances in relation to the trade refuse discharged from the trade premises either as regards volume or quality or chemical composition or otherwise the Trader shall pay to the

Corporation annually in respect of the reception and disposal of trade refuse and/or clean waters from his trade premises such reasonable sum or sums of money as having regard to the expense which the Corporation shall be put to thereby shall from time to time be agreed between him and the Corporation or failing agreement be determined as provided by Section 49 of the Act of 1915. Provided also that nothing in this Regulation shall be deemed to relieve any Trader from the obligation to comply with the provisions of these Regulations other than those numbered 2, 4, 5, 6, 7, 8, 9 and (so far as the same relates to a plan of Tanks) 13.

17. For the purpose of deciding any differences arising under these Regulations a Committee to consist (subject as hereinafter provided) of eight members shall be appointed annually—as to four of such members by the Corporation in the month of January, or as soon thereafter as possible—and as to the other four of such members by and at a meeting of the Traders which shall be summoned each year by not less than seven clear days' notice by advertisement in one or more newspapers circulating in the Borough and be convened by the Mayor of the Borough for the time being and be held in the month of January; provided that if either the Corporation or the Traders shall fail to appoint members of the said Committee as aforesaid the Committee shall consist of the members appointed by the Corporation and/or the Traders in the previous year; provided also that the said Committee shall act by a majority of those present and voting at any meeting; provided further that in case of an equality of votes on any question the Mayor of the Borough shall for the purpose of such question become and be a member of the Committee and his decision thereon shall be final; and provided also that the Town Clerk of the Borough shall act as the convener of and be responsible for the minutes of the meetings of the said Committee. No proceeding or decision of the Committee shall be questioned on account of any vacancy in that body but any vacancy shall be filled as soon as possible thereafter if the vacancy occurs amongst the members appointed by the Corporation, by the Corporation—but if the vacancy occurs amongst the members appointed by the Traders then such vacancy shall be filled by the remaining members appointed by the Traders.

APPENDIX B

PHENOL WASTES

GENERAL

During the last 20 years there has been a remarkable increase in the recovery and utilization of byproducts resulting from the purification of coal gas in gas house, coke oven and blast furnace operations. These byproducts have been exceedingly helpful in the development of the coal gas and coke industries, but, as is usually the case with almost all progress in industry, certain difficulties accompany each change and improvement in process.

The gas produced during the carbonization of coal is a mixture of fixed gases, vapors of various kinds and, at times, globules of liquid held in suspension and carried forward by the gas. The principal gases are hydrogen, methane, ethane, carbon dioxide, carbon monoxide, cyanogen, hydrogen sulphide, nitrogen, oxygen and ammonia. The principal vapors in the mixture are benzol, toluol, xylol, carbon disulphide, tar and aqueous vapors. These latter vapors contain naphthalene, phenols and other organic materials.

The principal residuals of this group recovered today are tar, naphthalene, cyanogen, ammonia and benzol. In some instances these constituents are of such great value to the coal gas producers that their treatment becomes a major part of the undertaking of the plant. In the coal gas industry these materials are removed as a rule by cooling the gas, condensing and precipitating the vapors as a fluid, and washing and treating the gases for the various materials to be recovered, under the different processes involved.

The details of these processes are not properly a matter of discussion in this place, but it should be pointed out that, as a result of these methods of recovery and extraction of valuable materials, local wastes of highly objectionable character are produced. The nature of these objections will be discussed in further detail below. The gas industry has changed in many directions of late years and with each change the quantity and

quality of waste liquor have created additional disadvantages to the receiving bodies of water and to those making use of such streams. One of the most important changes which has resulted in an increase of damage has been that the method of carbonization has been altered by the introduction of vertical instead of horizontal retorts. Comparatively little attention seems to have been paid to the methods of removal of tar and ammonia from the crude gas with the result that the repeated agitation of the tar with the ammoniacal liquor, which usually takes place in the recovery process, has given increased opportunity for the emulsification of tar constituents in the ammoniacal liquor.

Of the total effluent from the distillation of ammoniacal liquors by far the larger proportion is obtained direct from the still, the remainder being the "devil liquor" condensed from the saturator waste gases. The former is a brown liquor, turbid with particles of spent lime and tarry matter; it is heavily charged with acidic and basic tar oils and sulphur compounds. The devil liquor, in addition to pyridine, hydrogen sulphide, carbonic acid, and hydrocyanic acid, contains a notable amount of phenoloid bodies.

Table 1

Fowler, Ardern and Lockett	Parts per million	Skirrow	Parts per million		Per cent of total oxygen absorbed
				Oxygen absorbed in 3 minutes	
"Phenols"	1,401	Tar acids	2,120	2,847	52.0
Thiocyanate (CNS)	1,538	Thiocyanate (CNS)	2,250	1,827	33.3
Thiosulphate (S)	468	Thiosulphate (S)	640	530	9.7
Oxygen absorbed:					
4 hours	4,994	Ferrocyanide (as sodium salt)	280	5	0.1
3 minutes	3,339				
Ammonia:					
Free and saline	128	Other bodies (by difference)	....	269	4.9
By alkaline permanganate	142				
				5,478	100.0

The volume of liquor discharged from the ammonia distillation process is related primarily to the fixed ammonia content of the liquor distilled, which varies widely, not only in liquors of different origin (coke oven, gas works, etc.) but also in liquors of the same class.

The composition and properties of spent liquor from gas works were fully investigated by Skirrow and by Fowler, Ardern and Lockett in 1911. A summary of their findings is shown in Table 1, since the quantities are closely comparable with those still obtained.

Unfortunately in this, as in other industrial wastes problems, the logical course of obviating the production of excessive amounts of objectionable effluents has not been adopted. On the contrary, effort has been directed, not towards the reduction but towares the treatment of wastes which are unnecessarily noxious. Improvements in this branch of gas plant practice would result in measurable reduction of the quantities of liquor discharged, and would in turn create much less difficulty in their final treatment.

Older Methods of Disposal of Wastes

Until comparatively recently the complex mixtures, generally spoken of as "phenol wastes" have been disposed of at coke ovens and gas manufacturing plants by passing them through sedimentation and skimming tanks for cooling and for the removal of suspended tars and oils and then discharging into nearby streams. In some instances, the wastes have been led upon the land in the endeavor to have the liquors percolate through the soil and thus to purify themselves. Owing to the fact that the liquors carry a considerable amount of suspended material such as lime and other compounds, most soils usually become quickly clogged and the liquor wastes then pass off into neighboring watercourses with little or no change in character. More modern methods of disposal will be discussed below.

Harmful Effects of Wastes

Odors.—Frequently when the phenol wastes are permitted to flow to the nearest water course, in open ditches and undiluted, considerable odor arises, particularly in the summer on damp days. These are mostly due to the slow conversion of complex phenol compounds to simpler ones on oxidation with the air, which results in the production of free phenols.

Interference with Normal Uses of Streams.—Phenol wastes contain such a large proportion of materials foreign to natural bodies of water that they need very great dilutions in order to prevent endangering the usefulness of streams for various industrial and domestic purposes. Phenol wastes increase the

hardness of water and destroy its usefulness for washing, cooking, watering of stock and its use for irrigation purposes. Aside from their high content of quick lime, their phenol, as well as cyanide, contents make the use of a water containing considerable proportions of them highly dangerous for many domestic or industrial purposes where man, animal or plant life is involved.

Interference with Quality of Drinking Water.—In 1923 the State Boards of Health of Indiana, Illinois, New York, Ohio, Pennsylvania, West Virginia and Wisconsin reported over 50 public water supplies affected in a deleterious fashion by the discharge of wastes from gas works, producer gas plants, by-product coke ovens and industries receiving the products of these plants and extracting chemicals for further distillation and separation processes. The number of complaints is continually on the increase in this country as well as in practically every other industrial country in the world. The primary objection to these wastes, in the case of water supplies, has been that they impart an odor and taste of creosotes or phenols to practically all waters, unless the dilutions are of an order in excess of one part of phenol to several million parts of water. Unfortunately, these tastes and odors are considerably accentuated by the chlorination of the water supply, due to the formation of chlorophenols or other substitution products. Persistence of the taste in dilutions as great as 1 part of waste to 10 million parts of water or as far as 70 miles below discharges into streams has been reliably reported. The water supplies of Milwaukee, Cleveland, Chicago, Youngstown, Newcastle and many others in this country have been seriously affected at one time or another by taste and odor due to phenol wastes.

Disturbance of Biological Life.—The influence of phenol wastes in sufficient concentration upon the fauna and flora of streams is destructive. The released quick lime as well as the phenol itself may destroy the plankton of the water. The compounds of cyanogen are highly toxic, while the stable and toxic pyridine bases also create damage. As a result of these effects the entire biological equilibrium of a stream may be instantaneously disturbed through excessive discharge of phenol wastes therein.

With respect to higher forms of life, emphasis should be placed upon the toxic effect of phenol wastes in general upon fish life. Not only are these liquors toxic to fish life, but even in high dilutions they exert an objectionable effect upon fish by imparting to

them such disagreeable tastes and odors that the sales value of the fish is considerably reduced. Serious difficulties in this direction have been experienced on the Continent in both Germany and Holland, as long ago as 1912. So objectionable were these results that these and other conditions led to the establishment of a phenol commission to study the origin and treatment of coal tar wastes in general in the Emscher, Ruhr and Rhine districts of Germany.

Color.—Unfortunately experience has shown that even the removal of the bulk of phenol from the effluent of many works, particularly where liquids from vertical retorts are distilled, does not result in the complete elimination of objectionable materials, particularly of a color-producing nature. Sufficient thiocyanate, thiosulphate and "higher tar acids" remain to render the liquors highly objectionable from the point of view of final disposal.

The liquors with and without removal of phenols are highly colored and on exposure to the air may free themselves from suspended matter, but not from objectionable black color.

High Oxygen Demand.—The spent liquors under discussion have further objectionable aspects in that their demand for oxygen places a considerable burden upon receiving bodies of water when the diluting quantity is not considerable. Here again, progress in the industry has militated against advantageous stream control, in that the liquor from the older horizontal retorts were perhaps half as objectionable in their oxygen requirements as those emanating from the newer vertical retorts. This fact is well illustrated in a summary of typical effluents of the two types of plants given in Table 2 herewith.

TABLE 2

Liquor from Storage Well

	Horizontal retorts			Vertical retorts		
	Parts per hundred	Oxygen absorbed* parts per million		Parts per hundred	Oxygen absorbed* parts per million	
Phenol, as C_6H_5OH	0.162	2,900		0.327	5,800	
Thiocyanate, as CNS	0.240	1,950	= 3,200	0.216	1,800	= 5,500
Thiosulphate, as S	0.072	600		0.045	400	
Other forms (including color producing bodies) by difference	.....	650		.....	3,300	
	.....	6,100		.....	11,300	

* At 4 hours, 27° C.

These results were obtained in England during 1924 by the government agencies in charge of the inspection of coke oven and gas purification plants. They may be found in the sixty-first Annual Report on Alkali Works by the Chief Inspectors of the Ministry of Health of England and to the Scottish Board of Health, 1924. These figures are sufficient to indicate that the liquors are of a strength many times that of ordinary domestic sewage and that their consequent demand upon the receiving stream is excessive.

Effect on Sewage Treatment Processes.—More and more evidence is accumulating that gas house wastes delivered to municipal sewers and passing to sewage treatment plants are creating difficulties in operation and in some instances have necessitated complete shutdown of biological purification devices for considerable periods of time. Sanitarians are agreed that, when these liquors are received intermittently in sufficient amounts at activated sludge plants, it is almost impossible to avoid complete destruction of the biological medium in use. Recovery in the process consumes considerable time and is frequently obtained only after the gas works wastes have been diluted or removed. This aspect has been pointed out at greater length in preceding chapters in the text.

Even with ordinary biological methods of one type or another it is impossible to purify reasonable amounts of coal tar liquors without considerable dilution and without intermittent seeding of the filters with biological life. The effect on sewage treatment processes has been so serious in many areas, not only in the United States, but in Germany and England, that much thought is now being given to adequate methods of treatment of phenol wastes or to their delivery at municipal sewage treatment plants in greater dilutions and at much minimized rates of flow.

Methods of Disposal of Phenol Wastes

General.—In the consideration of practicable methods of disposing of the treated phenol wastes, it is desirable to refer again to the fact that the general term "phenol wastes" includes a series of chemical compounds which must be treated in different ways in order to accomplish the best results. By and large, there are perhaps four primary sources of pollution in coal tar liquors of gas works and coke oven origin. These are, respec-

tively, phenol, thiocyanate, thiosulphate and color-producing bodies and other compounds.

The phenols proper are perhaps the most noxious constituents of the normal effluents of spent liquors from ammonia plants. The toxicity of phenol is higher than that of thiocyanate, even though the oxygen requirements of both types of wastes may approach each other in quantity. It frequently happens that the ammonia still acts as a preliminary dephenolator and phenol thus removed should not be allowed to mix with the general body of spent liquors from the plant. The so-called "devil liquors" coming from a sulphate of ammonia plant contain, therefore, a high proportion of phenols with relatively inappreciable quantities of thiocyanate and thiosulphate. Where the devil liquors may be easily separated from the total spent liquor of the plant, they are suitable for evaporation either by spraying on the grate bars of the gas producers in the retort house or into the retort furnace flue.

In Table 3 the comparison between the phenol contents of devil liquor and effluent from the stills is well exemplified for two English plants of two different types. At Works A noted in Table 3, the volume of the devil liquor is 10 per cent of the total

TABLE 3.—PHENOL IN EFFLUENT SPENT LIQUOR FROM THE AMMONIA STILL, AND IN DEVIL LIQUOR FROM CONDENSING PLANT

	Works A			Works B
	Horizontal retorts			Vertical retorts
	Effluent from still exclusive of devil liquor	Devil liquor		Devil liquor
		"Hot"	"Cold"	
Volume, gallons per 24 hours....	10,300	620	520	
Temperature, ° C.....		88	48	63
Analysis, parts per hundred:				
Cyanide, as HCN.............	Nil	0.002	0.015	0.025
Sulphide, as H_2S.............	Nil	0.002	0.020	0.050
Phenol, as C_6H_5OH...........	0.200	0.552	0.807	0.760
Oxygen absorbed (4 hour-test) parts per million..............	7,800	10,300	16,400	15,400

effluent from the plant. Of the total phenol in the effluent liquor, 27 per cent is in the devil liquor and 73 per cent in the still effluent proper. The beneficial effect that results from the evaporation of the devil liquor is more marked in the case of vertical retorts, inasmuch as the phenol content there is much higher.

With reference to the origin of the thiocyanate as a mineral constituent of ammoniacal liquors, authors differ. It is considered by some to be an oxidation product due to the interaction of ammonium sulphide, cyanide and oxygen in the cooler parts of the condensing system. Control of the formation of excessive amounts of thiocyanate may therefore lie in reduction of oxygen and cyanide compounds of the crude coal gas entering the washers and scrubbers and by protecting the liquor from undue contact with air during storage. Likewise, considerable thiocyanate may result from the purifier liquors where its isolation for separate treatment has not been carefully provided for.

Inasmuch as thiosulphate is likewise an oxidation product, the conditions favoring its formation are similar to those noted for thiocyanate. Both reduction in oxygen content and protection of the liquor during storage against air contact should be practiced.

The higher tar acids, the color-producing bodies and all non-volatile oxygen-absorbing constituents make up the difference between the total oxygen absorption content of spent liquor and that accounted for by phenols, thiocyanates and thiosulphates. In the case of liquors from vertical retorts, it is apparent from the data shown in Table 3 that the removal from the liquor of higher tar acids and other constituents is, next to the removal of phenol itself, the most urgent problem confronting us.

TABLE 4.—AMMONIACAL LIQUOR FROM STORAGE

	Total oxygen absorbed, parts per million
(1) Liquor stored 5 weeks in contact with tar, with frequent disturbance	9,000
(2) Liquor distilled practically as made, towards end of run	5,000
(3) Liquor (2), after further 4 weeks in well	8,500

Contact of tar and liquor in the condensing plant and storage wells undoubtedly accounts for increased solution of these objectionable constituents by the ammonical liquor. This is again strikingly confirmed by the data shown in Table 4, representing the observations by the manager of a large gas works in the Midlands, England, where vertical retorts are in operation.

Complete separation of tar and liquor as made and their subsequent storage in separate wells would therefore appear to be the first step necessary for the production of a better character of liquor.

These general considerations all point to the necessity of changes and improvements in the industrial process, which might lead to the delivery of a more satisfactory type of spent liquor which would be more easily susceptible to ordinary forms of treatment. Some of the methods so far tried, with more or less success in individual cases, are therefore noted below for their suggestive character. No effort will be made to give these processes in detail because they involve aspects of industrial chemistry of coal tar liquors which are much too detailed to find a place in a text of this character.

At the end of this Appendix, a brief bibliography is given which will assist the reader in locating more complete references to the methods discussed below.

On Land.—One of the oldest and one of the most obvious methods of attempting to dispose of spent liquors is that of running the material on available land. Owing to the peculiar character of these wastes, it has been found impossible to dispose of the material on land excepting where all the conditions of porosity and acreage of land, removal of suspended matter, cooling of liquors and all other conditions incident to disposal have been of the most favorable character.

Quenching of Coke.—The use of spent liquors for quenching or cooling of glowing coke drawn from ovens has been adopted by a considerable number of industrial plants in the United States. The liquors thus pass into the air in clouds of steam. As an excess of the water is sprayed over the coke at a high rate, a portion is not evaporated at once but passes through the coke into sumps beneath the quenching platform. It is recirculated by pumps to be evaporated during subsequent quenching of charges of coke.

This process has not found very wide application on either the Continent or in England. The reasons therefor are stated to be that such procedure merely consists in vaporizing the phenols with the water and dissipating them into the atmosphere where portions are again condensed and collect on surrounding territory, subsequently to be washed into the stream by natural rainfall. As a matter of fact, considerable evidence has been produced within the past year to indicate that at times coal tar tastes and odors in public water supplies may originate from the solution in the atmosphere of phenols from neighboring industrial plants, which are deposited in streams during heavy rains. In addition, quenching of coke with these liquors sometimes results in rapid deterioration of quenching equipment due either to corrosive compounds contained in the still wastes or formed during quenching. On occasions discoloration and disagreeable odor are imparted to the coke, which may interfere with its sale for domestic purposes. If suspended calcium salts exist in the still wastes, clogging of the coke pores may result and this, in turn, prevents free burning of the surface coke.

A more important objection to the disposing of liquors by quenching is that raised by German operators that the vapors produced in such a procedure are detrimental to the health of coke-oven workers engaged in the neighborhood. This last consideration has probably militated most strongly against the adoption of quenching on the Continent.

Evaporation.—In some plants it is possible through proper arrangement of equipment to evaporate certain portions of the liquors which contain considerable amounts of phenols. In such instances, in the case of vertical retort products, the removal of 30 to 40 per cent of the total phenols might be effected by evaporation with a reduction in the total oxygen demand figures of perhaps 20 to 25 per cent. This procedure is practicable, however, only in those instances where separation of liquors has been so well accomplished that the quantity of material to be evaporated does not become excessive with resulting lack of economy.

Dephenolating Towers.—Considerable success has been had in both England and Germany in the decolorization and reduction of oxygen-absorbing power of effluent liquors by treatment with boiler fire gases and steam in a suitable scrubber. At the same time, a large portion of the phenoloid bodies is volatilized, so that a deodorized and almost colorless effluent, suitable for

admission to sewers, is obtained. This process has been in use since 1921 at the Hornsey Gas Works in England for treatment of the entire effluent liquor produced in the manufacture of 2½ to 3 tons of sulphate of ammonia per 24 hours. The spent liquor at the Hornsey works is from a horizontal retort and has an oxygen absorption figure at 4 hours at 27° C. of about 3000 parts per million.

Other works involving dephenolating towers have been built in England and have given reasonably satisfactory performance. Some difficulty has been experienced, where unusual amounts of free lime were in the spent liquor from the ammonia stills. This difficulty has been overcome by blowing the hot liquors with a certain amount of fire gases at the point of entry to the settling basins. The precipitation of the excess lime here has had the further advantage of promoting coagulation and removal, in the settling tanks, of something like 50 per cent of coloring matter due to higher tar acids. The addition of alumino-ferric solution to the hot liquors also promotes clarification and may be useful in the case of subsequent treatment with scrubbers and towers.

In the case of vertical retort liquors, good removal of monohydric phenols has been effected in dephenolating towers. Unfortunately, however, polyhydric phenols, with strong coloring properties and high oxygen absorption values, still remain to be dealt with. In addition, high contents of thiocyanate and thiosulphate make treatment of such liquors by dephenolation only partly successful. The process results, however, in the production of an effluent which is much more likely to be successfully dealt with by municipal sewage treatment plants than the original liquors ordinarily familiar to us.

Benzol Extraction.—This method consists simply in extracting phenol from waste liquors with benzol. It has been used with a reasonable degree of success in both England and Germany. Phenol is recovered from the benzol extract by means of a solution of caustic soda. Plants of this type are in operation in this country at the Hudson Valley Coke and Products Corporation at Troy, N. Y., at the National Tube Company plant at Lorain, Ohio, and at the Iroquois Gas Corporation plant at Buffalo, N. Y.

The system consists of pumping the crude ammonia liquor through a succession of extractors in which 90 per cent benzol or motor fuel is passed in the opposite direction by being pumped

into spray distributor pipes submerged in the ammonia liquors at the bottom of each ammonia liquor extractor. By means of this continuous countercurrent extraction system, desirable conditions for maximum extraction efficiency are fulfilled. Actual tests at the Troy plant show an extraction efficiency for phenols of 95 to 99 per cent.

The benzol acts as a transfer medium taking the phenol from the ammonia liquor and delivering it to the caustic soda. Sodium phenolate is formed and free phenols are liberated from the steamed phenolate solution by neutralizing with sulphuric acid or carbon dioxide gas from some convenient source. At Troy the carbon dioxide method is used because the sodium carbonate solution generated in neutralization can be used as make-up for a Koppers liquid purification unit, used for desulphurizing coke oven gas.

At the Troy plant, with a crude ammonia liquor containing 2 grams of phenol per liter, which is about the average, the products recovered are approximately, per thousand gallons of liquor, 18 pounds of sodium carbonate and 16.6 pounds of crude phenols. As far as we are aware, this method of phenol recovery has been highly successful, barring minor difficulties with the apparatus and shutdowns in plant due to unexpected breakdowns. The unrecovered phenols at the plant are discharged into the lime sump, the effluent of which is sprayed over the incandescent coke. Some liquors leave the plant at Troy from that portion thereof engaged in the manufacture of water gas. This has occasioned some difficulty in the stream, and recommendations for its evaporation at the coke quenching tower have since been made.

Use for Boiler Feed Water or for Recirculation.—At some gas manufacturing plants the waste waters from the gas washing chambers are freed of suspended tars and oils in sedimentation and skimming tanks and the effluent water is recirculated through the process to extract additional oil and tar from the gas. The oil and tarry deposits in these tanks form the base for the road oils on highways and represent a considerable profit in operation.

At one large Pennsylvania plant, where operation does not permit the constant recirculation of water, the excess water is used in the plant boilers, after treatment by sedimentation and coagulation, followed by filtration through coke strainers and sand filters. The savings in water costs to this plant are consider-

able, inasmuch as the gas company had previously purchased boiler feed water from the municipal supply.

Chemical Precipitation.—Efforts to improve the quality of spent liquors by the application of various forms of coagulating chemicals have not been particularly helpful, owing to the large amounts of precipitants necessary and to the fact that such clarification and precipitation do not result in sufficient removal of objectional materials to warrant the costs. In some instances these settling basin effluents have been led through filters of one form or another, but here again costs and operating difficulties have been great. Alumino-ferric, lime and iron and other forms of precipitants have been employed. In one or two instances copper and lime, sedimentation and double filtration through coke contact beds and gravel sand filters have been tried.

In England, for example, a large scale experiment was conducted at one of the gas works by adding 12 pounds of alumino-ferric to 10,000 gallons of effluent, after prior treatment of the hot liquors with fire waste gases in the settling pit. Only 14 per cent reduction in phenols, 40 per cent in color-producing bodies and 4 per cent in 4-hour oxygen absorbed figures were obtained.

Bacteria Beds.—As far back as 1911, Fowler, Ardern and Lockett experimented with the bacterial purification of ammonia liquors in England. Their work was carried out at the Manchester Gas Works and at the Corporation Chemical Works of Bradford. They found that phenol is more rapidly oxidized on a bacterial filter than thiocyanate, the products of oxidation being most probably carbonic acid and water. In 1907 Frankland and Silvester made valuable contributions to our knowledge of the properties of these liquors in relation to bacterial life, by determining the oxidation requirements of the chief ingredients of spent liquors. Further work has since been carried out by Maclean Wilson and Read, of the West Riding of Yorkshire Rivers Board, on the treatment of these waste liquors on a matured percolating filter. Their experiments indicate:

1. That a spent gas liquor, diluted until the oxygen absorbed in 4 hours is 4000 parts per million, is amenable to biological treatment.

2. That one filtration of this liquor at the rate of 15 gallons per cubic yard per day of 8 hours reduces the oxygen absorbed by 90 to 95 per cent, and removes 95 per cent of the thiocyanate,

yielding a highly nitrated effluent (at times containing as much as 10 parts of nitric nitrogen per hundred thousand).

3. A further filtration of this effluent on a similar filter at the rate of 12 gallons per cubic yard per day of 8 hours gives an effluent free from thiocyanate and absorbing less than 20 parts of dissolved oxygen per million.

Experiments of a similar nature on the biological treatment of effluents has been carried out by the technical staff of the Chief Alkali Inspector's Office of the Ministry of Health of England. The filter material used consisted of matured coke from one of the gas works in the London area. The tower was packed with clinker consisting of 9 inches of 2- or 3-inch boiler clinker on the bottom plate, 5 feet 9 inches of 1-inch screened clinker above and 5 feet 6 inches of ½-inch screened clinker on the top. The filter material was activated by mixing the boiler clinker with a small proportion of cow dung. Clear water was then circulated for a few days to spread the organisms prior to commencement of operations. In each case the feed liquor to be treated was obtained by diluting 1 volume of crude effluent from the ammonia still with 9 volumes of filtered treated effluent. The results obtained indicated that satisfactory purification of the diluted effluent is effected when the rate of flow of the liquid is maintained at about 70 gallons of diluted effluent per cubic yard per day. Approximately 94 per cent of the phenol of the crude effluent, 87 per cent of the thiocyanate and 96 per cent of the 4-hour oxygen absorbed values are removed by this process. The work so far done indicates that purification may be accomplished through such bacterial bodies, provided a sufficiently dilute material is passed through them, the beds are properly and continuously seeded with necessary bacterial forms and effort is made to prevent excessive deposits and undue concentrations of wastes on the bed. The disadvantage of the process lies largely in the exceedingly low rates applicable to the beds and the resultant high costs of operation.

Approximately the same findings are reported by Helbing and Bach in the extensive experiments which they have been carrying on in the Emscher district during the past 10 years. They obtained almost complete elimination of phenol odor and a reduction of 60 to 90 per cent in permanganate oxygen consumed.

Activated Sludge Process.—A working scale phenol removal plant is being operated by Imhoff and Sierp in the Oelbach

district of the Ruhr Valley on the coal tar wastes adjacent to the coal mine at Lothringen. At this plant a tar and oil catcher consisting of a baffled deep tank is inserted on the effluent line before the activated sludge plant is reached. The tank is equipped with an air pressure pipe on the bottom through which air is pumped to bring the tar and oil to the surface where it is skimmed off. The coal tar waste is first led into a small two-story tank where it is mixed with ordinary domestic sewage in the proportion of 1 part of waste to 9 parts of house sewage. The aeration tanks are of the spiral flow type and the amount of air used so far approximates three times that which would be used for domestic sewage alone. The results indicate a 99 per cent removal of phenol and the plant has been in operation about 9 months. Its performance has been frequently disturbed by excessive amounts of oil and tar which have at times destroyed the activated sludge efficiency to such a degree that it was difficult to resume operations. It is doubtful whether this method of handling the problem is likely to find very widespread adoption, owing to the high operating costs and the sensitiveness of the process to slight disturbances in seeding and in concentration of coal tar liquor entering the plant.

Copeland had shown at Milwaukee some years ago, however, that the activated sludge process was entirely effective when the volume of phenol wastes in municipal sewage did not exceed 3 per cent. Where the effort is made appreciably to increase the relative amount of phenol to be treated success becomes less probable.

Aerated Contact or Emscher Filter.—A more interesting device for removing phenol liquors is located near the coal mine Helene in the Essen district. This plant has been installed and is under the supervision of Bach of the Emscher district and consists of an ordinary contact filter supplied with compressed air by means of feed pipes 1 foot apart on the bottom of the bed. The phenol wastes are mixed with house sewage, with a dilution of four to seven times obtained from the effluent of the beds. This particular device, which was in operation in 1926 on a large scale, made use of an air supply very much in excess of anything comparable with domestic sewage purification. The removal of phenols was complete. The construction and operating costs, however, were quite large and would probably necessitate modification and improvements in the process before general

adoption could be considered. Improvements have been suggested in the construction of new beds to make more intensive use of the media of the bed and by employing moving rather than stationary air supply pipes on the bottom. At this writing it is not possible to state whether the fixed and operating charges on such a plant, confirmed by long term operation, make it a practicable installation. At any rate it indicates an additional procedure which might be adopted for situations which need immediate and prompt treatment of these objectionable materials.

In addition to the processes enumerated above, attempts at elimination of phenols have been made through reduction by hydrogen, coke oven, or natural, gas and a catalyst, preferably copper. Oxidation by ozone has been suggested as well as the use of hypochlorite for decolorization. Bone black, lignites and peat have been used for the same purpose.

Road Dressings

In the discussion so far presented, no reference has been made to the influence of coal tar compounds on adjacent streams due to the washings from highways which have been dressed with such mixtures. Little emphasis upon this situation has been evidenced in the United States, but considerable work has been done by the Ministries of Agriculture and Fisheries in England in the endeavor to determine upon the extent and nature of the damage which might be done to fish through washings from road dressings. So far has this program advanced in England that the Subcommittee on Roads' Dressings of the Committee on Stream Pollution of the Ministries of Agriculture and Fisheries has issued a report indicating opposition to the use of tar dressings on roads near streams and suggesting the substitution of bitumen as a road surface in these particular instances. Although their recommendations have met with considerable opposition by the manufacturers of tar products for road surfaces, the subcommittee still insists that, in view of the damage done to fish life and of the fact that lengths of roads adjacent to streams represent such a small per cent of the total length of roads, their recommendation for the elimination of tar dressings works no hardship upon the industry.

These facts are mentioned here merely as an indication of the nature of operations abroad, so that in our studies of destruction

of fish life we may have before us all of the possibilities of causative agents involved.

General Conclusions

It may be fairly observed, as the result of the general survey of the situation confronting sanitarians, from the effects of spent liquors from gas works and coke oven plants, that the composition of the liquors may be profitably modified by the conditions under which condensation is effected and by the manner of storage. Unfortunately, in the past the attention of the gas works operators has been directed almost exclusively to the operation of the plant, in the way of purification of crude coal gas. This situation was perhaps not so dangerous when horizontal systems of retorts were in use with relatively smaller quantities of spent liquors. Now that vertical retort installations are on the increase and effluent liquors from stills are causing more and more concern to sewage works operators and administrators in control of streams, there is considerable reason for objecting to the continuation of the old conditions.

Aside from these facts, there is considerable evidence to sustain the conclusion that effluent spent liquors in general are highly polluting in character and, therefore, their origin should be so carefully controlled as to reduce to a minimum their quantity, in so far as this is possible, without undue charge upon the industry. Simultaneously with such endeavors on the part of the industry, additional work is necessary to develop some form of treatment of the spent liquors, when they have been reduced to a minimum, which will eliminate the conditions set forth in detail above. The facts here noted indicate certain directions in which such work may be started and others in which definite forms of treatment are available. The material can be only suggestive, rather than final, by virtue of the fact that neither the industry nor the sanitary engineer is in a position at this writing to offer ultimate and satisfactory solutions to all the difficulties involved.

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